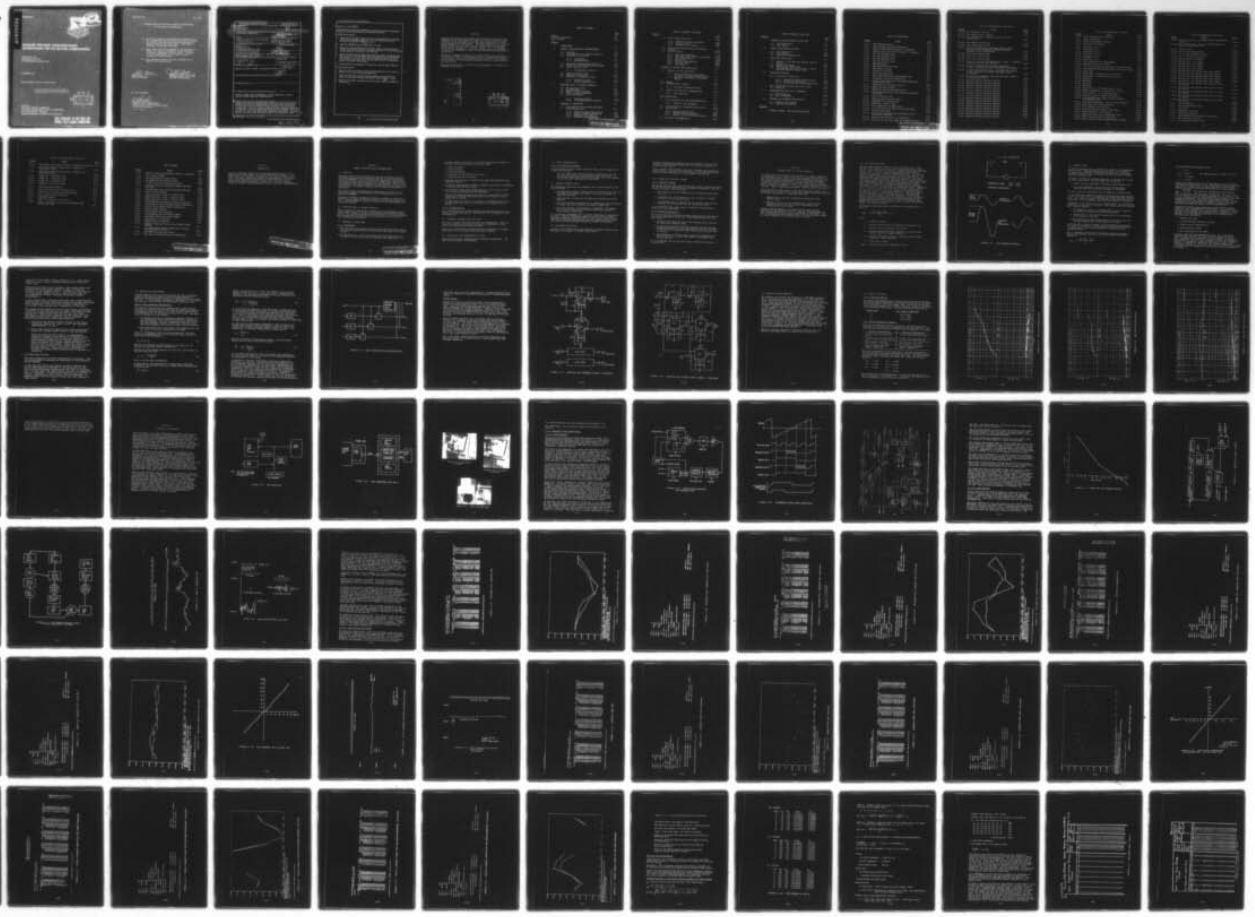
AD-A035 033 HONEYWELL INC ST PETERSBURG FLA AEROSPACE DIV F/G 17/7
STANDARD PRECISION NAVIGATOR/GEANS MODIFICATIONS FOR EAR MOTION--ETC(U)
NOV 76 D GIONET, P E HALL, S SAMSEL F33615-74-C-1068
UNCLASSIFIED 176-13551 AFAL-TR-76-71 NL

1 OF 5
AD A035033



ADA035033

AFAL-TR-76-71



STANDARD PRECISION NAVIGATOR/GEANS MODIFICATIONS FOR EAR MOTION COMPENSATION

HONEYWELL INC.
AEROSPACE DIVISION
ST. PETERSBURG, FLORIDA 33733

NOVEMBER 1976

FINAL REPORT JUNE 1974 - JANUARY 1976

Approved for public release; distribution unlimited

DDC
RECEIVED
FEB 1 1977
D

Prepared for
AIR FORCE AVIONICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

AFAL-TR-76-71 July 1976

STANDARD PRECISION NAVIGATOR/GEANS MODIFICATIONS FOR EAR MOTION COMPENSATION

(1) This final report was submitted by Honeywell Inc. St. Petersburg, Florida under Contract No. F33615-74-C-1068 to the Air Force Avionics Laboratory, Wright Patterson Air Force Base. John Cogan, AFAL/RWM, was Project Engineer.

(2) This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

(3) This technical report has been reviewed and is approved for publication.

John Cogan
Project Engineer

RICHARD W. SMITH, Lt Col, USAF
ADP-1206 Program Manager

For The Commander

ROBERT E. DEAL, Actg Asst Chief
Reconnaissance & Weapon Delivery Division
AF Avionics Laboratory

AIR FORCE - 22 DECEMBER 76 - 75

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: AFAL-TR-76-71	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)*: STANDARD PRECISION NAVIGATOR/GEANS MODIFICATIONS FOR EAR MOTION COMPENSATION.	5. TYPE OF REPORT & PERIOD COVERED: Technical Final technical rept. Jun 74 — Jan 76
	6. PERFORMING ORG. REPORT NUMBER: T76-T3551
7. AUTHOR(s): Daniel Gionet, Paul E. Hall, Steven Samsel	8. CONTRACT OR GRANT NUMBER(s): F33615-74-C-1068 new
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Honeywell, Inc. Aerospace Division St. Petersburg, Florida 33733	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 63241F 12060109
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Avionics Laboratory Reconnaissance & Weapon Delivery Div. AFAL/RWM Wright-Patterson AFB, OH 45433	12. REPORT DATE: November 1976
	13. NUMBER OF PAGES: 355
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*: 279 p.	15. SECURITY CLASS. *(of this report)*: Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release: distribution unlimited. 1206 01

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

inertial guidance, motion compensation, velocity resolution, vibration isolation, gimbal angle data, transmissibility

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

STANDARD PRECISION NAVIGATOR/GEANS MODIFICATIONS FOR EAR MOTION COMPENSATION summarizes the technical accomplishments of the Modification Study Program for the period from the Preliminary Design Review 20-21 June 1974 through 1 January 1976. The study program included the design, brassboard fabrication, and functional testing of proposed modifications to the SPN/GEANS to meet the Electronically Agile Radar (EAR) motion compensation requirements. The design, analysis, and testing show these modifications to be feasible and readily →

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

H03190 AB

adaptable to the SPN/GEANS.

The modification to enable a SPN/GEANS to perform the EAR motion compensation requires the following hardware and software modifications:

Hardware Modifications --

1. Change the IMU isolator transmissibility to provide improved low frequency acceleration measurement capability. This will require raising the present 16 Hz isolator frequency to 40 Hz.

2. Adapt the SPN/GEANS gyro to withstand 20 g's shock.

3. Redesign the VMU Pulse Rebalance Electronics (PRE) circuitry to provide 0.00125 ft/sec/pulse ΔV resolution (present resolution is 0.04 ft/sec/pulse). Two PRE boards, No. 1B and No. 2, are involved.

4. Redesign the IMU logic to accept high resolution ΔV data, and provide high data rate (256 Hz) ΔV and gimbal angle data transmission to the EAR Radar Data Processor. This will require design changes to one existing logic circuit board and the addition of one new board, which will increase the depth of the overall logic package.

5. Develop special test equipment to functionally check the 256 Hz data bus.

Software Modifications --

1. Expand the SPN Serial Data Bus output to provide additional 32 Hz data to EAR for initialization and motion compensation.

2. Modify the BSFM, DECD, and BITE software modules to accept the new ΔV format and incorporate improved gimbal angle readout accuracy in DECD.

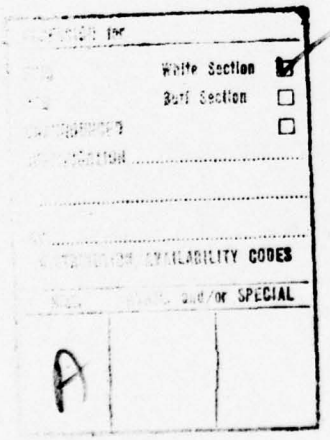
3. Modify the CDU module to expand entry and display of precision checkpoint coordinates.

PREFACE

STANDARD PRECISION NAVIGATOR/GEANS MODIFICATIONS FOR EAR MOTION COMPENSATION is the final technical report on a study program for modifications to the SPN/GEANS to meet EAR (Electronically Agile Radar) motion compensation requirements. The report summarizes the technical accomplishments of the program for the period from the preliminary design review, 20 June 1974, through 1 January 1976. It discusses the brassboard fabrication, functional testing, and proposed modifications to the SPN/GEANS in order to meet the EAR motion compensation requirements.

Technical information related to the study program, and originally contained in Technical Coordination Letters, is summarized in Section 9 of the report. Section 9 also presents the results of measurements and calculations of accelerometer nonlinearity due to torque generator reaction torque.

The software listing for the EAR Data Record Module is included as an appendix to the report.



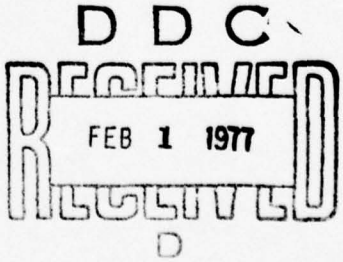


TABLE OF CONTENTS

		Page
Preface		iii
List of Illustrations		ix
List of Tables		xvii
Section		
1	INTRODUCTION	1-1
2	SUMMARY CONCLUSIONS AND RECOMMENDATIONS	2-1
	2.1 Overview	2-1
	2.2 Increased Gyro "G" Support Capability	2-1
	2.3 Increased ΔV Resolution	2-1
	2.3.1 Conclusions	2-1
	2.3.2 Recommendations	2-2
	2.4 Increased ΔV/Gimbal Angle Data Rate	2-2
	2.5 System Level IMU Transmissibility Tests	2-2
	2.6 Static Isolator Tests	2-3
	2.6.1 Conclusions of Testing	2-3
	2.7 Resolver Accuracy Tests	2-3
	2.8 Additional Design Data	2-3
	2.9 Software and Interface Liaison	2-4
	2.9.1 Interface Liaison	2-4
	2.9.2 Software Modification	2-4
3	INCREASED GYRO "G" SUPPORT CAPABILITY	3-1
	3.1 ESG Suspension Theory	3-2
	3.2 Tradeoff Study	3-4
	3.3 Adaptive Bias Development	3-9
	3.4 Status of Effort Completed	3-15
	3.5 Final Test Results	3-16
	3.5.1 Vibration Testing	3-16
	3.5.2 Drift Repeatability Testing	3-16
4	INCREASED ΔV RESOLUTION	4-1
	4.1 High Resolution Pulse Width Modulated Accelerometer Loop	4-5
	4.1.1 Technical Circuit Description	4-5
	4.1.2 Status of HRPWM Loop Testing	4-12
	4.1.3 Brassboard Test Results	4-12
	4.1.4 Technical Recommendations	4-54

PRECEDING PAGE BLANK-NOT FILMED

TABLE OF CONTENTS (Continued)

Section			Page
	4.2	Hypha Interpolator Loop	4-86
		4.2.1 Technical Circuit Description	4-86
		4.2.2 Status of Effort	4-91
		4.2.3 Brassboard Test Results	4-91
	4.3	Test Console Changes and Data Processing Hardware	4-157
	4.4	Trade-Off Study	4-178
		4.4.1 Test Data Comparison	4-178
		4.4.2 Additional Parts Needed to Implement	4-178
		4.4.3 Power Requirements	4-183
		4.4.4 Reliability	4-183
		4.4.5 New Part Types Required	4-183
		4.4.6 Technical Risks	4-183
		4.4.7 Cost Impact	4-184
5	INCREASED ΔV/GIMBAL ANGLE SAMPLE RATE		5-1
	5.1	Technical Circuit Description	5-1
		5.1.1 The High Resolution Pulse Width Modulator ΔV Readout Circuit Design	5-1
		5.1.2 The Hypha Interpolator ΔV Readout Design	5-4
	5.2	Status	5-4
	5.3	Brassboard Test Results	5-4
		5.3.1 Slip Ring Transmission Test	5-4
	5.4	Summary and Technical Recommendations	5-12
		5.4.1 Slip Ring Test	5-12
6	EARS SYSTEM TESTS		6-1
	6.1	Test Description for IMU Transmissibility	6-6
		6.1.1 Vibration Test Equipment	6-14
	6.2	Current Status of Transmissibility Tests	6-21
	6.3	Test Results	6-22
		6.3.1 Isolator Repeatability	6-22
		6.3.2 Maximum Sway of Isolators	6-22
		6.3.3 Analysis of Vibration Test Results	6-22
	6.4	Technical Recommendations	6-42

TABLE OF CONTENTS (Continued)

Section		Page
7	VIBRATION ISOLATOR STABILITY WITH TIME	7-1
	7.1 Test Description	7-2
	7.2 Test Results	7-6
8	GIMBAL ANGLE READOUT ACCURACY	8-1
	8.1 Test Description	8-5
	8.2 Test Results	8-8
	8.3 Technical Recommendations	8-19
9	ADDITIONAL DESIGN DATA	9-1
	9.1 Impact of 16 Hz Data Rate Between Computer and IEU	9-2
	9.2 Gimbal Servo Errors	9-4
	9.3 IMU Mass and Inertia Data	9-6
	9.4 Accelerometer Non-Linearity Due to Torque Generator Reaction Torque (TGRT)	9-8
10	RELIABILITY PROGRAM	10-1
	10.1 Reliability Program Plan	10-1
	10.1.1 Reliability Education/Orientation	10-1
	10.1.2 Reliability Predictions	10-1
	10.1.3 Parts Selection and Standardization	10-2
	10.2 Design Requirements Check List (DRCL)	10-2
	10.3 Reporting	10-2
11	MAINTAINABILITY AND COST OF OWNERSHIP	11-1
	11.1 Maintainability	11-1
	11.2 Cost of Ownership	11-2
12	SOFTWARE AND INTERFACE WITH EAR RDP	12-1
	12.1 Interface with EAR RDP	12-1
	12.2 Software Requirements	12-3
Appendix		
	SOFTWARE LISTING - EAR DATA RECORD MODULE	A-1

LIST OF ILLUSTRATIONS

Figure	Title	Page
3.1-1	ESG Suspension Theory	3-3
3.3-1	Basic Variable Preload Mechanization	3-11
3.3-2	Adaptive Bias Reference Source (1 Required)	3-13
3.3-3	Adaptive Bias Typical Error Channel (3 Required)	3-14
3.5-1	Run 2603 Residual Drive	3-17
3.5-2	Run 2604 Residual Drift	3-18
3.5-3	Run 2605 Residual Drift	3-19
3.5-4	Run 2602 Residual Drift	3-21
4.0-1	EARS Brassboard	4-2
4.0-2	EARS Brassboard Test Setup	4-3
4.0-3	VMU Block in Fixture	4-4
4.0-4	VMU Block in Fixture	4-4
4.0-5	Accel Loop Test Stand	4-4
4.1-1	Pulse Width Modulated Accelerometer Loop	4-6
4.1-2	Incremental Pulse Width Modulation	4-7
4.1-3	Original High Resolution Pulse Width Modulated Accelerometer Loop	4-8
4.1-4	HRPWM Open Loop Transfer Function	4-10
4.1-5	HRPWM Loop Block Diagram	4-11
4.1-6	HRPWM Loop Forward Loop Electronics	4-13
4.1-7	EAR Program Technical Review EAR High Resolution ΔV Testing	4-14
4.1-8	Best 1g Stability Run	4-15
4.1-9	EARS High Resolution Loop Data	4-16
4.1-10	SPN/GEANS Full Linearity Run	4-18
4.1-11	HRPWM Full Linearity Run	4-24
4.1-12	Null Deadband Run on GEANS Loop	4-30
4.1-13	8/1/75 Stability Run EAR Loop with SPN Board	4-31
4.1-14	Linearity Test Data	4-33
4.1-15	9/22/75 Null Deadband Test SPN Baseline Data - 600 Second Count Time	4-39
4.1-16	Stability Run EAR Loop with HRPWM Board	4-41
4.1-17	Initial Linearity Tests with New HRPWM Brassboard	4-42

PRECEDING PAGE BLANK-NOT FILMED

LIST OF ILLUSTRATIONS (Continued)

Figure	Title	Page
4.1-18	Data Samples at 256 Hz	4-49
4.1-19	Data Sample Rate = 2048 Hz	4-52
4.1-20	Data Sample Rate = 2048 Hz 11/21/75 + 1g Tc = 1,048,576 Hz	4-53
4.1-21	Data Sample Rate 256 Hz	4-55
4.1-22	Data Sample Rate 256 Hz	4-56
4.1-23	11/17/75 Linearity Run Modified SPN Loop High Resolution Div. Head Angle Versus RMS Count Deviation 256 Hz Sample Rate	4-57
4.1-24	Data from 2,048 Hz Rate	4-59
4.1-25	Data from 2,048 Hz Rate	4-61
4.1-26	Data from 2,048 Hz Rate	4-63
4.1-27	Modified SPN Loop High Resolution 1 Pulse = 0.0003125 ft/sec 0g (90 deg) 200 Records	4-65
4.1-28	11/18/75 Modified SPN Loop High Resolution 1 Pulse = 0.0003125 ft/sec 86 degrees 200 Records	4-66
4.1-29	11/18/75 Modified SPN Loop, High Resolution Forced 1 Pulse Deviation for Worst Case Spec, 86 deg 200 Records	4-67
4.1-30	11/21/75 Null Deadband, Modified SPN Loop, LOPHA II 40 Second Count Time	4-68
4.1-31	Spectral Density Analysis Results	4-71
4.1-32	Spectral Density Analysis Results	4-72
4.1-33	Spectral Density Analysis Results	4-73
4.1-34	Spectral Density Analysis Results	4-74
4.1-35	Spectral Density Analysis Results	4-75
4.1-36	Spectral Density Analysis Results	4-76
4.1-37	Spectral Density Analysis Results	4-77
4.1-38	Spectral Density Analysis Results	4-78
4.1-39	Spectral Density Analysis Results	4-79
4.1-40	Spectral Density Analysis Results	4-80
4.1-41	Spectral Density Analysis Results	4-81
4.1-42	Spectral Density Analysis Results	4-82
4.1-43	Spectral Density Analysis Results	4-83
4.1-44	Spectral Density Analysis Results	4-84
4.1-45	Spectral Density Analysis Results	4-85

LIST OF ILLUSTRATIONS (Continued)

Figure	Title	Page
4.2.1	Block Diagram Hypha Interpolator	4-87
4.2-2	Hypha Interpolator	4-89
4.2-3	Hypha Loop Transfer Functions	4-92
4.2-4	Simulated 0g Waveforms	4-93
4.2-5	Simulated +2.5 g's	4-94
4.2-6	Simulated +5 g's	4-94
4.2-7	Simulated +10 g's	4-95
4.2-8	Simulated -2.5 g's	4-95
4.2-9	Simulated -5 g's	4-96
4.2-10	Simulated -10 g's	4-96
4.2-11	Test Connections for Loop Response	4-97
4.2-12	Expanded View of B5-6 Output	4-98
4.2-13	Plot of Loop Output Voltage Versus Input Frequency	4-99
4.2-14	Interconnection Between Brassboard and Hypha Circuit	4-101
4.2-15	Hypha Loop	4-103
4.2-16	Hypha Board - 40 Second Counts 10/29/74	4-104
4.2-17	Hypha Board - 40 Second Counts 10/30/74	4-105
4.2-18	Waveforms	4-106
4.2-19	Waveforms	4-106
4.2-20	Waveforms	4-107
4.2-21	Waveforms	4-107
4.2-22	Hypha Loop +1g 40 Second Counts 11-1-74	4-108
4.2-23	Hypha Interpolator - Linearity Run 11-3-75	4-110
4.2-24	Dynamic Errors - 50 Hz BW Hypha Loop	4-112
4.2-25	Analysis Approach - Hypha Loop Errors	4-113
4.2-26	50 Hz BW Hypha Loop Dynamic Errors Compared to Allowable Error	4-114
4.2-27	Allowable Acceleration - Error Versus Frequency	4-115
4.2-28	Hypha Loop Error Transmissibility	4-116
4.2-29	Sine Vibration Specification	4-117
4.2-30	Wind Gust Spectral Density 4 PPS Input	4-118
4.2-31	Random Vibration Specification	4-119
4.2-32	Hypha Loop Error Due to Sinusoidal Input	4-120
4.2-33	Hypha Loop Errors Due to Wind Gusts	4-121
4.2-34	Hypha Loop Error Due to Random Vibration Input	4-122

LIST OF ILLUSTRATIONS (Continued)

Figure	Title	Page
4.2-35	Hypha Loop Data +lg 360 Second Counts (with Dither) 9-15-75	4-123
4.2-36	Null Deadband Test, EAR Loop with SPN Board and Hypha 40 Second Count Time	4-124
4.2-37	Linearity Data	4-125
4.2-38	Plot of Long Term Stability	4-135
4.2-39	Plot of Null Deadband Test Data	4-137
4.2-40	Plot of Linearity Test Data	4-139
4.2-41	Mod SPN Loop 0 g's (Hypha)	4-142
4.2-42	Mod SPN Loop 0 g's (Hypha)	4-143
4.2-43	Mod SPN Loop 0 g's (Hypha)	4-144
4.2-44	Mod SPN Loop 0 g's (Hypha)	4-145
4.2-45	Mod SPN Loop 0 g's (Hypha)	4-146
4.2-46	Mod SPN Loop (86 Degrees) Worst Case (Hypha)	4-147
4.2-47	Mod SPN Loop (86 Degrees) Worst Case (Hypha)	4-148
4.2-48	Mod SPN Loop (86 Degrees) Worst Case (Hypha)	4-149
4.2-49	Mod SPN Loop (86 Degrees) Worst Case (Hypha)	4-150
4.2-50	Mod SPN Loop (86 Degrees) Worst Case (Hypha)	4-151
4.2-51	Mod SPN Loop (86 Degrees) Worst Case W/l Pulse Dev (Hypha)	4-152
4.2-52	Mod SPN Loop (86 Degrees) Worst Case W/l Pulse Dev (Hypha)	4-153
4.2-53	Mod SPN Loop (86 Degrees) Worst Case W/l Pulse Dev (Hypha)	4-154
4.2-54	Mod SPN Loop (86 Degrees) Worst Case W/l Pulse Dev (Hypha)	4-155
4.2-55	Mod SPN Loop (86 Degrees) Worst Case W/l Pulse Dev (Hypha)	4-156
4.3-1	EARS Brassboard	4-158
4.3-2	EAR Brassboard Test Setup	4-159
4.3-3	AFCS Board	4-161
4.3-4	SPN/GEANS Loop Board	4-163
4.3-5	HRPWM Board Schematic	4-165
4.3-6	EAR Brassboard Accelerometer Block Wiring	4-167
4.3-7	EAR Brassboard Test Cable	4-169
4.3-8	EAR Brassboard Control Panel	4-171

LIST OF ILLUSTRATIONS (Continued)

Figure	Title	Page
4.3-9	EAR Brassboard Processor Board	4-173
4.3-10	Accelerometer Data Processing Block Diagram	4-177
4.4-1	VMU Mods Needed for Hypha	4-185
4.4-2	VMU Mods Needed for HRPWM	4-186
5.1-1	Method A HRPWM ΔV Data System	5-2
5.1-2	Method B HRPWM ΔV Data Method	5-3
5.1-3	ΔV Readout Block Diagram for Hypha Interpolator Concept	5-5
5.1-4	ΔV Readout Circuit Design for Hypha Interpolator Concept	5-6
5.3-1	Slip Ring Test I	5-8
5.3-2	Slip Ring Test I	5-9
5.3-3	Slip Ring Test II	5-10
5.3-4	Slip Ring Test II	5-11
5.3-5	Slip Ring Test III	5-13
5.3-6	Slip Ring Test III	5-14
6-1	1/2 g Input	6-2
6-2	1 g Input	6-3
6-3	Random Input	6-4
6-4	Accelerometer Placement and Axis Indication	6-5
6.1-1	GEANS on Holding Fixture for Vertical Vibration	6-7
6.1-2	Orthogonal Gimbal Position	6-8
6.1-3	Slewed Gimbal Position	6-9
6.1-4	Accelerometer Placement on Inner Element	6-10
6.1-5	Vertical Axis Vibration Position	6-12
6.1-6	Close-Up Showing Placement of One Set of Mirrors	6-13
6.1-7	16 Hz Isolator (1/2 g Sine) Vertical Axis	6-15
6.1-8	40 Hz Isolator (1/2 g Sine) Vertical Axis	6-16
6.1-9	35 Hz Isolator (1/2 g Sine) Vertical Axis	6-17
6.1-10	30 Hz Isolator (NOAH)(1/2 g Sine) Vertical Axis	6-18
6.1-11	30 Hz Isolator (SPRING)(1/2 g Sine) Vertical Axis	6-19
6.3.3-1	Measured Transfer Function, 16 Hz Isolators, Vertical	6-28
6.3.3-2	Measured Transfer Function, 16 Hz Isolators, Longitudinal	6-29
6.3.3-3	Measured Transfer Function, 16 Hz Isolators, Lateral	6-30

LIST OF ILLUSTRATIONS (Continued)

Figure	Title	Page
6.3.3-4	Theoretical Transfer Function, 16 Hz Isolators, Isolator Resonant Frequency Adjusted to Match Experimental 1/2 g Result, Gimbal Damping Varied to Try to Match Q's, 2 Spring-Mass-Damper Model	6-31
6.3.3-5	Theoretical Transfer Function, 16 Hz Isolators, Isolator Resonance Modeled at 20 Hz, 5 Spring-Mass-Damper Model with Structural Damping	6-32
6.3.3-6	Measured Transfer Function, 35 Hz (Butyl) Isolators, Vertical	6-33
6.3.3-7	Measured Transfer Function, 35 Hz Isolators, Longitudinal	6-34
6.3.3-8	Measured Transfer Function, 35 Hz Isolators, Lateral	6-35
6.3.3-9	Theoretical Transfer Function, 35 Hz Butyl Isolators, Frequency and Q Adjustment to Match Measured Response, 5 Spring-Mass-Damper Model	6-36
6.3.3-10	Measured Transfer Function, 40 Hz Isolators, Vertical Axis	6-37
6.3.3-11	Measured Transfer Function, 40 Hz Isolators, Longitudinal Axis	6-38
6.3.3-12	Measured Transfer Function, 40 Hz Isolators, Lateral	6-39
6.3.3-13	Theoretical Transfer Function, 40 Hz Isolators, 5 Spring-Mass-Damper Model with Structural Damping	6-40
6.3.3-14	Vibration Model	6-41
7.1-1	Vertical Mode	7-3
7.1-2	Horizontal Mode	7-3
7.1-3	Test Piers	7-4
7.1-4	Test Instrumentation	7-4
7.1-5	Isolator Test Stands	7-5
7.2-1	EAR Isolator Test Vertical Mode	7-7
7.2-2	EAR Isolator Test Horizontal Mode	7-8
8.0-1	Histogram of Resolver Errors Using Tangent Bridge Readout	8-3
8.1-1	Diagram of Gimbal Mount on Rotation Table	8-6
8.1-2	Gimbal Angle Readout Interface	8-7
8.1-3	Typical Data Output	8-9
8.2-1	SPN Gimbal Angle Accuracy Loop 2(System Excitation)	8-10
8.2-2	SPN Gimbal Angle Accuracy-Loop 4 (System Excitation)	8-11

LIST OF ILLUSTRATIONS (Continued)

Figure	Title	Page
8.2-3	SPN Gimbal Angle Accuracy-Loop 3 (System Excitation)	8-12
8.2-4	SPN Gimbal Angle Accuracy-Loop 3 (Wavetek P.S. Excitation Input)	8-13
8.2-5	SPN Gimbal Angle Accuracy-Loop 3 (HP200CD P.S. Excitation Input)	8-14
8.2-6	Gimbal No. 1 Accuracy Data	8-15
8.2-7	Gimbal No. 2 Accuracy Data	8-16
8.2-8	Gimbal No. 3 Accuracy Data	8-17
8.2-9	Gimbal No. 4 Accuracy Data	8-18
9.1-1	Processor Mechanization	9-3
9.2-1	Open Loop Gain Versus Frequency K_oG_o	9-5
9.2-2	Closed Loop Gain Versus Frequency K_cG_c	9-5
9.2-3	Error Angle Versus Frequency	9-5
9.3-1	SPN/GEANS Gimbals	9-7
9.4-1	TGRT as a Function of Frequency	9-9
12.1-1	Signal Interfaces, EAR RDP and SPN/GEANS INS, B-52 Flight Test	12-2

LIST OF TABLES

Table	Title	Page
3.2-1	Impact of Design Approaches to Double G Capability	3-6
3.2-2	Test Results Summary	3-7
3.5-1	Drift Repeatability Test Results	3-20
4.1-1	SPN/GEANS Five-Day Stability Test	4-40
4.1-2	ΔV Data Processing Display Description	4-48
4.1-3	Accelerometer Loop Performance Summary Modified SPN Loop	4-69
4.1-4	Accelerometer Loop Linearity Modified SPN Loop	4-69
4.1-5	Velocity Noise Summary	4-70
4.2-1	Hypha Loop Data 1 Pulse = 0.00125 ft/sec	4-131
4.2-2	Hypha Loop Data 1 Pulse = 0.00125 ft/sec	4-132
4.2-3	Hypha Loop Data 1 Pulse = 0.00125 ft/sec	4-133
4.2-4	Accelerometer Loop Linearity Hypha Interpolator	4-141
4.2-5	Accelerometer Loop Performance Hypha Interpolator	4-141
4.2-6	Velocity Noise Summary Hypha Interpolator	4-141
4.4-1	Velocity Noise Summary	4-179
4.4-2	Accelerometer Loop Linearity	4-180
4.4-3	Accelerometer Loop Performance Summary	4-181
4.4-4	Comparison Table Hypha Versus HRPWM	4-182
6.3-1	Repeatability of Isolators	6-23
6.3-2	Maximum Sway of Isolators	6-26
8.0-1	Summary of Resolver Errors Using Tangent Bridge Readout	8-4
9.1-1	Loop Phase Margin Versus Sample Rate, Lag Time and Compensation Corners	9-2
9.3-1	SPN/GEANS Gyro Mass and Inertia	9-7
12.1-1	RDP Inputs from INS for Motion Compensation	12-4

PRECEDING PAGE BLANK-NOT FILMED

Section 1

INTRODUCTION

This Final Technical Report on the SPN/GEANS Modifications for the Electronically Agile Radar (EAR) Motion Compensation Program, is provided to the U.S. Air Force in compliance with Contract F33615-74-C-1068. The report summarizes technical accomplishments on the Modification Study Program for the period from the Preliminary Design Review 20-21 June 1974 through 1 January 1976. It also contains a status of contract technical tasks, as well as technical recommendations.

PRECEDING PAGE BLANK-NOT FILMED

Section 2

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

2.1 OVERVIEW

The study program effort performed to date has included the design, brassboard fabrication and functional testing of proposed modifications to SPN/GEANS to meet the EAR motion compensation requirements. The design analysis and testing effort has shown these modifications to be feasible and readily adaptable to the SPN/GEANS. There is good correlation of analyses and circuit test data for the key functions of increased gyro "g" support capability and increased accelerometer ΔV resolution.

Test results from the demonstration reduced-gap gyro show that the EAR motion compensation requirements can be successfully met by a modified SPN/GEANS.

Honeywell, therefore, recommends a follow-on program to include the detail design, packaging and incorporation of these modifications into one or more SPN/GEANS, in support of the overall EAR development and evaluation program.

2.2 INCREASED GYRO "G" SUPPORT CAPABILITY

There is excellent correlation of theoretical and demonstrated parameters, both in terms of circuit characteristics and g-support capability. The increased g-support was verified with a modified SPN/GEANS gyro through shock testing and drift performance tests, and met the full performance requirements.

2.3 INCREASED ΔV RESOLUTION

2.3.1 Conclusions

1. Both the Hypha Interpolator and Pulse Width Modulated (PWM) methods of achieving higher resolution velocity data can achieve the desired results.

2. The PWM method has a lower parts count and power requirement than the Hypha, with slightly better performance (see Subsection 4.4).

PRECEDING PAGE BLANK-NOT FILMED

3. The best method to be used in a particular application depends on several factors, including the following items:

   a. space available

   b. power available

   c. noise environment

   d. packaging and modification restraints

   e. manufacturing and test costs.

4. Attention must be paid to internal loop noise when designing high resolution loops.

5. A computer centered data collection system is practically a necessity in testing high resolution loops.

6. The PWM method would impact SPN/GEANS less in the areas of parts count, power requirements and new assemblies.

7. The Hypha Interpolator method can achieve a resolution of 0.00125 ft/sec with a maximum count deviation of 0.92 ft/sec at a data sample rate of 256 Hz.

8. The PWM method can achieve a resolution of 0.0003125 ft/sec with a maximum count deviation of 0.6 ft/sec at a data sample rate of 256 Hz.

2.3.2 Recommendations

It is recommended that the PWM method be utilized in modifying a SPN/GEANS for the EAR application. See Section 4 for the basis for this recommendation.

2.4 INCREASED ΔV/GIMBAL ANGLE DATA RATE

The circuit designs have been completed and breadboarded. These circuits were checked out with their respective brassboards by using them for collecting data during the tests.

Based on the test results, no major technical problems are foreseen with either the ΔV or gimbal angle data rate increases.

2.5 SYSTEM LEVEL IMU TRANSMISSIBILITY TESTS

These tests have been completed per the contract requirements. The data has been reduced, and analyzed.

2.6 STATIC ISOLATOR TESTS

2.6.1 Conclusions of Testing

From the results of the Isolator stability tests, the following conclusion can be drawn:

> In a horizontal mode, unmatched 40 Hz isolators moved 10 arc-seconds in one axis and 5 arc-seconds in the other axis. In the vertical mount mode the angular movement was 23 arc-seconds in one axis and 7 arc-seconds in the other.

2.7 RESOLVER ACCURACY TESTS

The conclusions drawn from the component level resolver accuracy test are as follows:

1. The same fourth harmonic characteristic was seen at this level as was observed in system level tests, with some differences in amplitude and phase.

2. Some reduction in amplitude occurred with external excitation supplies.

3. The fourth harmonic characteristic is predominant and well defined. It should lend itself readily to computer compensation.

4. The first harmonic, though smaller in amplitude, also appears to be easily defined on each axis and therefore capable of being software compensated.

It is therefore recommended that a software compensation technique be utilized. Software compensation appears, at this time, to offer a more direct and less costly solution to gimbal angle readout errors than does an extended investigation into the hardware characteristic and error sources and probable subsequent hardware modification.

2.8 ADDITIONAL DESIGN DATA

Section 9 of this report discusses additional technical aspects which developed as an adjunct to the EAR study program.

Interface considerations such as using a 16 versus 32 Hz data rate between an EAR-modified SPN/GEANS and the navigation computer are treated in this section.

Other technical data included in Section 9 includes IMU gimbal servo characteristics, IMU mass and inertia data, and the Torque Generator Reaction Torque contribution to accelerometer nonlinearity.

2.9 SOFTWARE AND INTERFACE LIAISON

2.9.1 Interface Liaison

During the course of this contract, the major signal interfaces between the EAR RDP and the SPN/GEANS were discussed and clarified. The conclusions arrived at were as follows:

1. The existing Navigation Computer will be preserved essentially as it is.

2. A separate IMU RDP interface bus will be added to transmit the 256 Hz ΔV and resolver data.

3. The SPN/GEANS program software will be modified for interface compatibility with the RDP via the IAU and mock ACUC.

It is recommended that these changes, discussed in more detail in Section 12.0, be implemented.

2.9.2 Software Modification

The existing SPN/GEAN Rolm-1602 software package will be modified for the motion compensation capability. These modifications fall into three areas:

1. To provide the interface data in the required format with the EAR Radar Data Processor (RDP).

2. To provide the modified BITE and diagnostic software for the hardware modifications to the IMU necessary for the increased ΔV resolution and increased gimbal angle readout and data rate to the RDP.

3. Implementation of a Kalman filter routine to accomplish navigation updating in the Rolm-1602 based on measurement data from the EAR RDP.

It is recommended that the detailed changes described in Section 12 be implemented.

Section 3

INCREASED GYRO "G" SUPPORT CAPABILITY

The EAR's application requires that the SPN gyro support capability be increased to 20 g's peak in the frequency range around 40 Hz. To meet this requirement a study program was conducted to determine the best approach, and a demonstration gyro was assembled and tested. Preliminary study and test results indicated that a 20.5 g support capability could be achieved. Tests of the final modified configuration, included in paragraph 3.5, confirm a support capability of 21.5 g minimum. (Refer to Final Test Results in this section of the report.)

During the EAR's study program it has been shown that either of two approaches will provide the increased rotor support capability required by the EAR's application. These approaches are:

1. Modification of the gyro suspension electronics to add adaptive bias.

2. Reduction of the rotor to electrode gap, increasing the maximum output of the high voltage transformers, and increasing the bias voltage.

Although approach number 2 is the one which has been pursued through shock demonstration and drift testing, both approaches and their background information will be presented in this report. To aid in understanding the tradeoffs made in selecting approach number 2, a brief discussion of suspension theory is given.

3.1 ESG SUSPENSION THEORY

The basic ESG suspension theory is shown in Figure 3.1-1. The electric force between the rotor and a single electrode is proportional to the square of the potential gradient between that electrode and the rotor. Control of the rotor-electrode charge directly controls the potential gradient, independent of gap. The force is directly proportional to the magnitude of the charge squared. The basic Honeywell ESG suspension consists of three identical sets of suspension electronics, one for each coordinate axis. Each axis has a pair of charge amplifiers (sometimes called current amplifiers) connected between a pair of diametrically opposing electrodes. Each pair of charge amplifiers has both a differential and a common mode input. Preload or bias signals, obtained from a balanced, three-phase source, are applied to the common mode inputs. Rebalance control signals derived from three rotor position sensing bridges, one for each suspension axis, are applied to the corresponding differential inputs. The rebalance charge is, therefore, added to the preload charge in one amplifier, of a pair, and subtracted from the preload charge in the other amplifier. Since the net force on the rotor along an axis is proportional to the difference in the squares of the magnitude of the charges between the two opposite electrodes, and the rotor, a linear relationship exists between this force and the rebalance signal, provided the preload signal is maintained constant.

The maximum theoretical support capability of the suspension is given by

$$A_{max} \quad \frac{aC_o h \ (E_{m+}^2 - E_{m-}^2)}{M}$$

where:

a = geometric constant

C_o = nominal centered rotor-to-electrode capacitance in pf

h = nominal rotor-to-electrode gap in mils

$m+$ = maximum electrode-to-rotor gradient in kilovolts peak per mil (K_V/mil) on upper electrode.

$m-$ = electrode-to-rotor gradient in kilovolts peak per mil (K_V/mil) on lower electrode.

M = rotor mass in grams

A_{max} = maximum acceleration capability in g's.

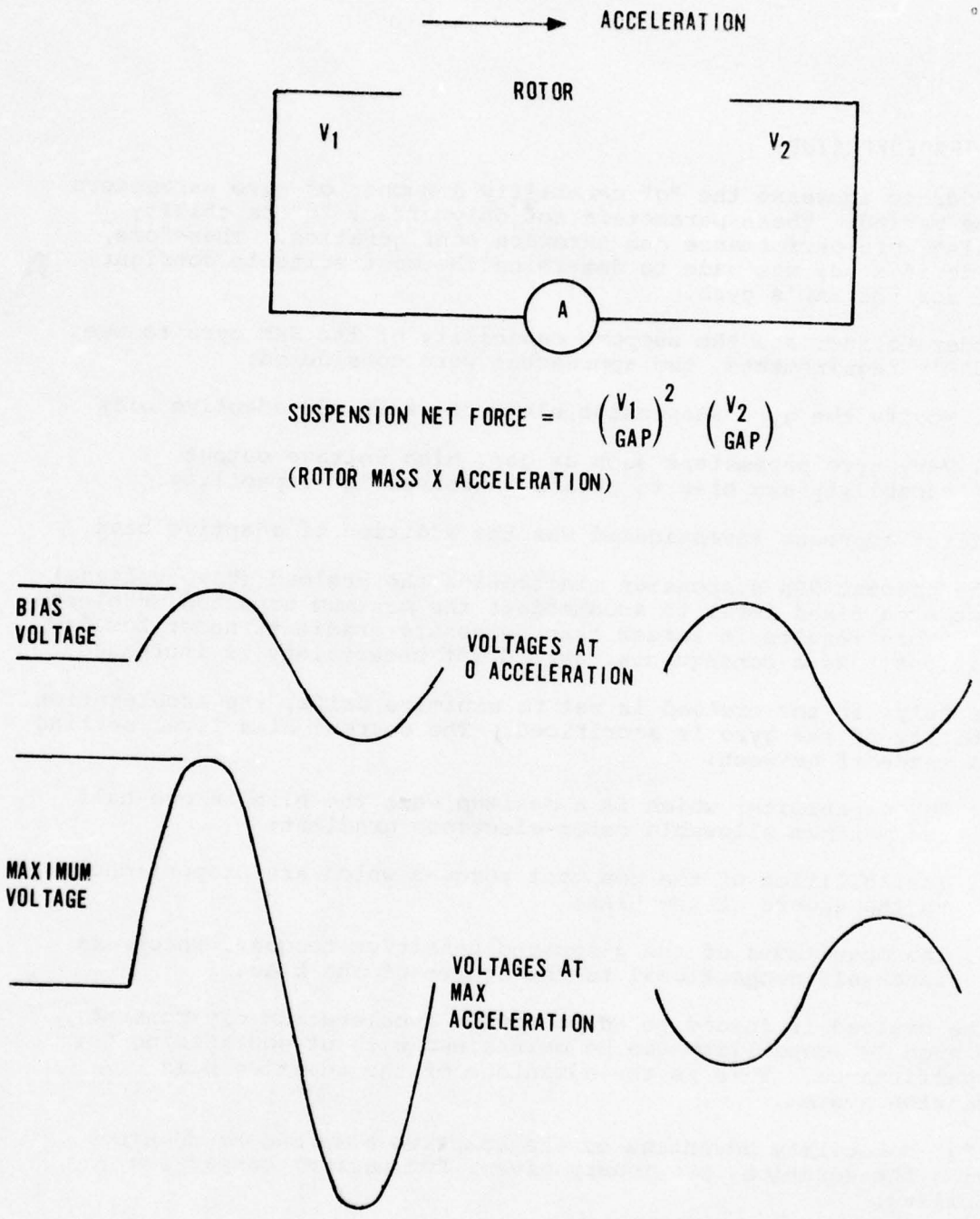


FIGURE 3.1-1. ESG SUSPENSION THEORY

3.2 TRADEOFF STUDY

In order to increase the "g" capability a number of gyro parameters can be varied. These parameters not only affect "g" capability but also gyro performance and hardware configuration. Therefore, a tradeoff study was made to determine the most suitable configuration for the EAR's gyro.

In order to increase the support capability of the SPN gyro to meet the EAR's requirements, two approaches were considered:

1. Modify the gyro suspension electronics to add adaptive bias
2. Vary gyro parameters such as gap, high voltage output capability and bias to obtain increased "g" capability.

The first approach investigated was the addition of adaptive bias.

In the present SPN suspension electronics the preload (bias voltage) is set at a fixed level to accommodate the maximum expected acceleration. This results in larger than necessary gradients under low "g" conditions. As a consequence, gyro drift uncertainty is increased.

Conversely, if the preload is set to minimize drift, the acceleration capability of the gyro is sacrificed. The current bias level setting was a tradeoff between:

1. "g" capability, which is a maximum when the bias is one-half the maximum allowable rotor-electrode gradient;
2. Instabilities of the constant torques which are proportional to the square of the bias;
3. The magnitudes of the g-squared-sensitive torques, which are inversely proportional to the square of the bias.

If the preload is forced to adapt to the acceleration environment, then high "g" capability can be maintained without sacrificing low "g" performance. This is the advantage of the adaptive bias suspension system.

The "g" capability advantage of the adaptive bias can be seen by solving the equation, previously given, for maximum suspension capability.

$$A_{max} = \frac{\alpha C_o h \left(E_{m+}^2 - E_{m-}^2\right)}{M}$$

The present SPN gyro parameters are:

α = 0.83

C_o = 130 pf Max support voltage = 2,000 volts peak

h = 1.79 mils

m = 10 gram

Substituting these values into the expression for A_{max} yields an acceleration capability of 17.3 g. When adaptive bias is used, the bias level is automatically increased when the lower electrode reaches cutoff (0V), such that the expression for A_{max} reduces to $A_{max} = \frac{aC_o h E_{m+}^2}{m}$. The theoretical maximum when using adaptive bias is then 24.6. The reduction in capability from 24.6 g's to 17.3 g's, despite the same voltage gradient of 1.11 kv/mil, is due to the canceling effect of the preload forces generated by the non-supporting electrode. The adaptive bias concept removes the canceling preload force from the nonsupporting electrode, thereby resulting in an approximately 4.8 percent increase in maximum acceleration capability without sacrificing performance.

Although the adaptive bias suspension provides maximum support capability with no degradation in performance, the circuit complexities cause increased cost and gyro size. Therefore, a second approach was considered for increasing the "g" capability of the SPN gyro. For this approach variation of the following gyro parameters were considered.

1. Reduce rotor mass
2. Increase maximum suspension voltages
3. Reduce rotor to electrode gap
4. Increased bias voltage
5. Some combination of the above

As can be seen from the expression for A_{max}, any of the above parameters may be varied to increase the "g" capability of the gyro. Although the "g" capability can be increased by varying gyro parameters, the impact on the hardware design, and performance must also be considered. Shown in Table 3.2-1 are the tradeoffs between "g" capability, performance and hardware impact. For comparison purposes (in the table), the impact on performance is based on doubling the "g" capability of the gyro by varying one parameter at a time.

TABLE 3.2-1. IMPACT OF DESIGN APPROACHES TO DOUBLE G CAPABILITY

Approach	Performance Impact	Hardware Impact
Rotor Mass Reduction	None	Difficult Rotor Fabrication
Increased Maximum Suspension Voltage	None	Moderate Hardware Redesign to accommodate Higher Voltages
Reduced Rotor Electrode Gap	2 X (Degradation)	Minor Circuit Changes
Increased Bias Voltage	8 X (Degradation)	Minor Changes
"Adaptive Bias"	0.5 X (Improvement)	Major Circuit Addition

To obtain test data to demonstrate 20 g support capability, a series of tests were conducted with SPN gyro 8S. During the test, three parameters were varied to determine the effects on "g" capability.

1. Rotor to electrode gap. The rotor-to-electrode gap was reduced by induction heating the rotor to increase its size while maintaining the envelope at a constant temperature.

2. H. V. output capability was increased. A special test module with high output high voltage transformers was used to increase the high voltage output capability from 4,000 to 5,000 v p-p.

3. Bias voltage increase. A special test module was used in which the bias voltage could be increased by adjusting a potentiometer.

A summary of the test obtained results are given in Table 3.2-2.

The test results obtained with SPN gyro 8S demonstrated that 20 g support capability is feasible with relatively minor hardware changes.

From Table 3.2-1, it is also apparent that decreasing the gap and increasing the bias voltage both degrade performance.

The fixed torque magnitudes are approximately proporational to the square of the voltage gradient. It is likely that some degradation in performance (probably about 40 percent) will result as the drift nonrepeatability is proportional to the magnitude of the fixed torques. Even though performance is degraded, it is expected that the SPN gyro modified to operate with reduced gap and increased bias will still perform within specification as the SPN gyros have typically performed at less than one-half the specification limit.

TABLE 3.2-2. TEST RESULTS SUMMARY

Test Condition	"g" of Test Device	Comment
Normal Gyro	15 g's	Rotor and envelope temp. were both 180 degrees F
Rotor heated to reduce gap	17.5 g's	Gap reduced 0.0023 as determined by the gap sensor
Used Special H.V. Module	18 g's	Rotor not overheated. 18 g's equivalent to 5,000 vpp
H.V. Module w/ Increased Bias	20 g's	Increased bias from 0.9 vrms to 1.0 vrms (feedback voltage)
Normal gyro (Reduced gap by heating)	17.5 g's	Rotor heated to reduced gap 0.0003 inch as determined by the gap sensor.
H.V. Module	20 g's	The rotor was heated to reduce gap (somewhere between 0.0002 and 0.0003 inch reduction)

Fabrication and Test of Demonstration Gyro

After completion of the suspension capability tests conducted with gyro 8S, an EAR demonstration gyro was assembled and tested. The purpose of the gyro was to demonstrate 20 g support capability and 0.0007 degree/hour/axis drift repeatability. The modifications to the gyro consisted of:

1. Reduced gap envelope assembly. A rotor was fabricated from isotropic beryllium which has a diameter 0.0006 inch larger than the rotor in gyro 8S. When assembled in an envelope, the rotor to electrode gap is 0.0003 less than the gap in gyro 8S. Isotropic beryllium was used to reduce any temperature induced drift stabilities.

2. High Output HIGH VOLTAGE TRANSFORMER

   Two design changes were made to the SPN gyro high voltage transformer to optimize it for use in the EAR's gyro. The first modification was to reduce the secondary winding from 1664 to 1542 turns to decrease the secondary inductance. This was necessary because the reduced gap for the EAR's mechanical assembly increases the gap capacitance, detuning the secondary. The reduction in secondary inductance was calculated to just offset the increase in gap capacitance so as to keep the LC product constant. The second modification was to reduce the number of primary turns from 27

(one-half of the center tapped primary) to 17. This change allows the peak to peak secondary voltage to be driven to 5,000 v p-p.

Reducing the primary turns increases the current which must be delivered by the power amplifier hybrid to drive the secondary to the required levels. In addition, detuning due to rotor motion induced by high g levels or cold soak at low temperatures further increases the primary current requirements.

At the present time, vibration tests have been conducted which indicate that the power amplifier hybrids do not have sufficient drive capability to drive the high voltage transformers to full output, thus limiting the g capability of the gyro.

The current drive capability of the output stage is primarily a function of the positive supply voltage, the LM101A op amps driving the output transistors, and the β of the output transistors. These three functions provide clues as to how the output stage current capability can be increased. Two modifications have been tested experimentally:

a. Increasing the positive supply voltage to the output hybrids by tapping the input to the 6 volt regulator (approximately 7.8 vdc).

b. Using power amplifier hybrids with output transistors having β's at least double those in the SPN hybrids.

These two modifications result in an approximate increase in output current drive of 50 percent which should be sufficient for all operating conditions. A third method of improving the current capability is to select the LM101's for output capability before installing them in the hybrids. Tests have shown a large unit to unit variation in the output characteristics of these devices. Tests are still in progress to finalize the output stage configuration for maximum "g" capability.

3. Increased Bias Voltage

The bias voltage was increased approximately 10 percent. This was accomplished by changing two components in the reference source assembly.

At the time this report was issued, vibration testing and circuit development as detailed in the description of the high voltage transformer modification were still in progress. 20.5 'g's peak have been demonstrated, but more "g" capability margin is desirable. Following the completion of vibration testing, repeatability drift testing will be conducted. A separate report will be issued to cover the final results of these tests.

3.3 ADAPTIVE BIAS DEVELOPMENT

Although adaptive bias is not being pursued for use in the EAR's system, significant development effort has been expended in designing the adaptive bias circuits and interfacing them with the SPN gyro. In the following paragraphs, a description of the adaptive bias concept, circuit design and development status are given.

Adaptive Bias Suspension Mechanization

The Adaptive bias suspension was designed with a fixed preload level for all inputs at or below the expected nominal acceleration environmental level (probably 1 to 2 g's), and will adapt itself to optimum bias for all accelerations above this level. The lower limit is necessary for two reasons:

1. To maintain loop gain and suspension dynamics constant for all acceleration levels, the circuit gain must increase as preload decreases. As preload approaches zero, the circuit gain must approach infinity. Therefore, to minimize high gain noise problems, there must be a lower limit on preload.

2. The preload would set at the ambient environmental level anyway, even if it had the capability to go lower.

To aid in understanding adaptive preload suspension, consider a single gyro suspension axis. The net electric force (F_x) along this axis can be expressed as:

$$F_x = K_1 Q_o Q_x \tag{1}$$

where K_1 is a constant of proportionality, Q_o and Q_x are the preload and rebalance charges, respectively.

Forming the force balance equation for this axis, and dividing by the rotor mass (M) gives:

$$a_i = \ddot{x} + \frac{K_1 Q_o Q_x}{M} \tag{2}$$

where a_1 is the input acceleration.

At this point in the derivation of a conventional fixed bias suspension, the rebalance charge Q_x is made linearly proportional to rotor sag as:

$$Q_x = K_2 G_2 x \tag{3}$$

where x is the rotor sag, K_2 is a gain constant, and G_2 is the dynamic portion of K_2 (i.e., lead, lag, etc.). Substitution of Equation 3 into Equation 2 and taking the LaPlace Transform (for quiescient initial conditions) gives:

$$\frac{x}{a_i} = \frac{1}{s^2 + \frac{K_1 K_2 G_2 Q_o}{M}} \tag{4}$$

It can be seen from Equation 4 that the system is linear and can be stabilized by appropriate choice of the gain and dynamic terms. It is also evident that Q_o affects the loop gain and, therefore, if this term is variable, the loop dynamics will vary with acceleration. This is undesirable since both sag and dynamic response must be rigidly controlled to minimize electric torque and rotor run-down rate, as well as to insure loop stability under all conditions of input acceleration.

It can be seen, looking back at Equation 2, that in reality the product $Q_o Q_x$ should be made proportional to the rotor sag if the preload is to be made variable. Suppose instead of linear loop compensation, a nonlinear compensation is used, such as:

$$Q_x = \frac{K_3 G_3}{Q_o} x \tag{5}$$

Upon going through the same steps as before, the relationship between sag and input acceleration becomes:

$$\frac{x}{a_i} = \frac{1}{s^2 + \frac{K_1 K_3 G_3}{M}} \tag{6}$$

It is evident from Equation 6 that the desired loop compensation has been achieved; that is, the loop gain and suspension dynamics are independent of bias change.

In addition to loop gain and dynamics, there is an additional constraint on preload Q_o. When the entire three suspension axes are considered, together with the three phase consideration, Q_o must be the same magnitude for all three axes. The preload will be optimally minimum if, along the axis sustaining the greatest acceleration, only the electrode pulling against the acceleration force is excited. This condition will result if the preload Q_o and rebalance Q_x charges are equal in this axis. A means of mechanizing this condition together with the condition of Equation 5 is shown by Figure 3.3-1. In this figure, e_o, e_x, e_y, and e_z are the preload and rebalance signals which control the charge amplifier

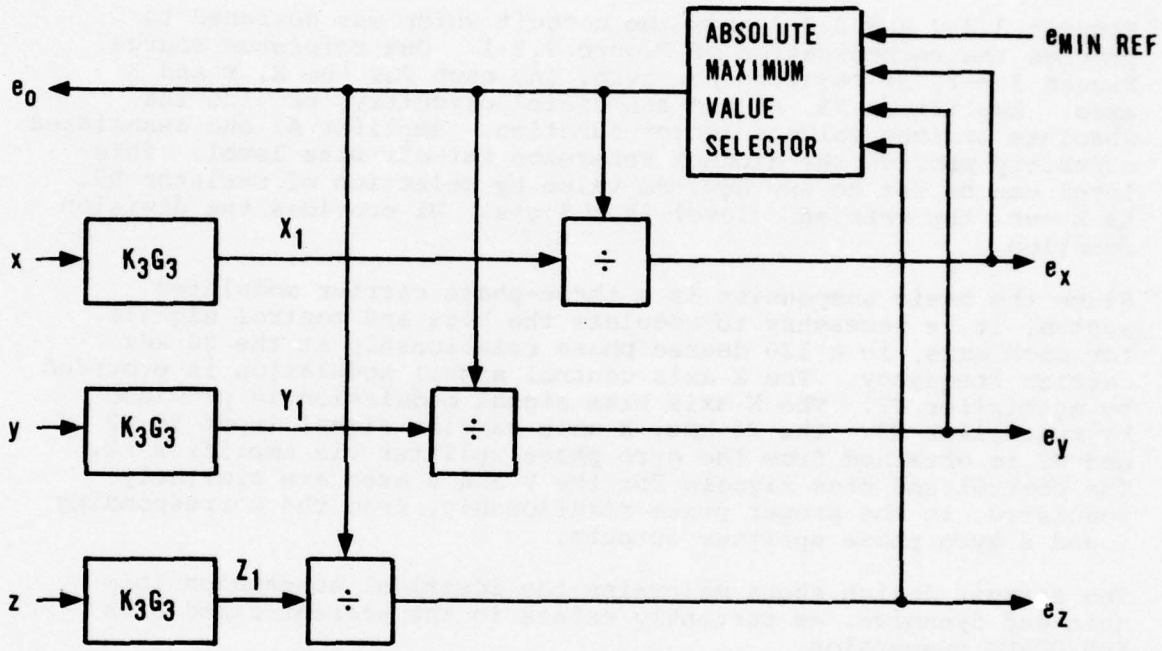


FIGURE 3.3-1. BASIC VARIABLE PRELOAD MECHANIZATION

outputs Q_o, Q_x, Q_y, and Q_z, respectively. A minimum reference level ($e_{min\ ref}$) constraint is placed on the preload for reasons mentioned before.

Circuit Design

Figures 3.3-2 and 3.3-3 show the circuit which was designed to provide the mechanization of Figure 3.3-1. One reference source, Figure 3.3-2, is required per gyro, one each for the X, Y and Z axes. Amplifiers A5, A6 and associated circuitry, provide the absolute maximum value selector function. Amplifer A1 and associated circuitry provide the minimum reference cut-off bias level. This level can be set to any desired value by selection of resistor R2. As shown, the reference level is 1.5 g's. U1 provides the division function.

Since the basic suspension is a three-phase carrier modulated system, it is necessary to modulate the bias and control signals, for each axis, in a 120 degree phase relationship at the 20 kHz carrier frequency. The X axis control signal modulation is provided by multiplier U2. The X axis bias signal modulation is provided by multiplier U3. The 20 kHz, X axis carrier signal input to U2 and U3 is obtained from the gyro phase splitter via amplifier A2. The control and bias signals for the Y and Z axes are similarly modulated, in the proper phase relationship, from the corresponding Y and Z gyro phase splitter outputs.

The circuit design shown maintains the identical suspension loop gain and dynamics, as currently exists in the present fixed bias SPN/GEANS suspension.

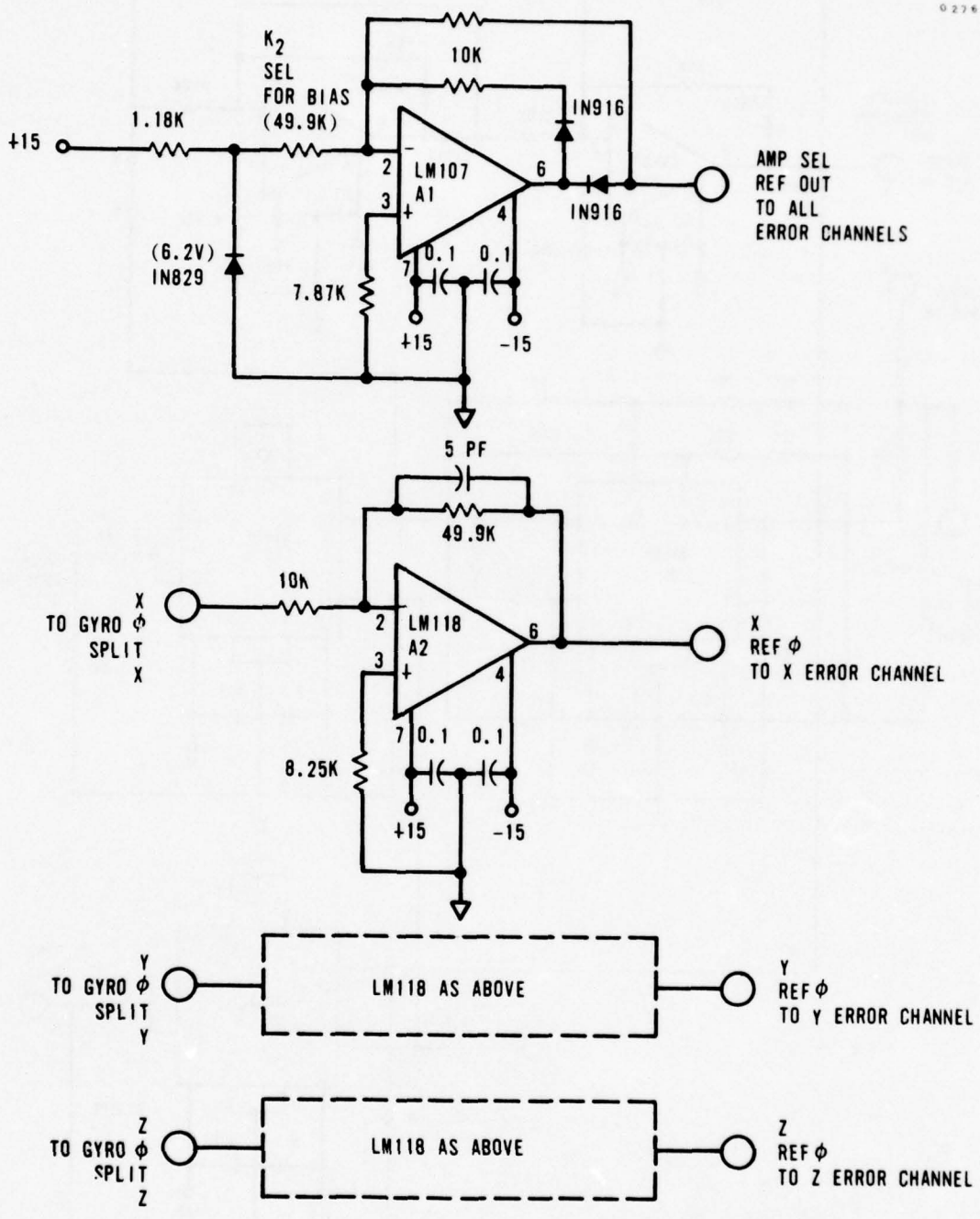


FIGURE 3.3-2. ADAPTIVE BIAS REFERENCE SOURCE (1 REQUIRED)

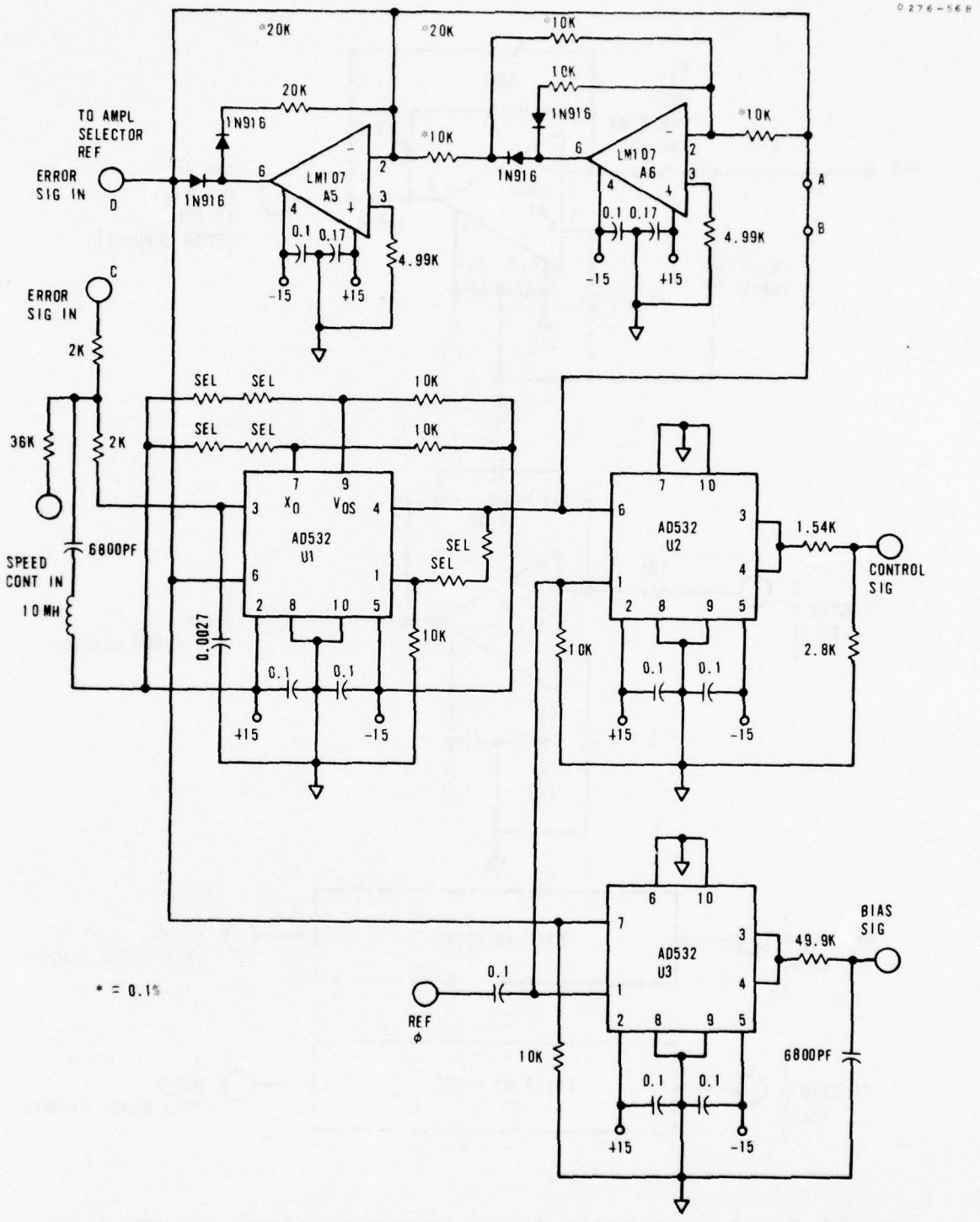


FIGURE 3.3-3. ADAPTIVE BIAS TYPICAL ERROR CHANNEL (3 REQUIRED)

3.4 STATUS OF EFFORT COMPLETED

The adaptive bias circuit was connected to a SPN/GEANS brassboard gyro. Initially the gyro rotor would not lift. The cause was traced to wiring errors and malfunctioning components within the gyro. These were corrected and the rotor was successfully suspended/ It was found necessary, however, to run with reduced loop gain because of excessive noise on the gyro X, and to a lesser extent Z, error signals. The noise was essentially random in nature and was not present on the Y error signal. Further investigation showed that the noise was caused by some type of nonlinear interaction at the basic suspension charge amplifier inputs. It was then found that this same phenomenon had been present in the original suspension, without adaptive bias, and that a filter impedance interface had been added to the charge amplifier inputs to correct it. The output of the X axis adaptive bias channel was then changed to operate through this interface and the noise diappeared from the X axis. Similar changes were then made for the Y and Z axes. However, in the process of modifying the Z axis, one of the gyro suspension modules was damaged. At this point the contract stop-work-order was received.

Results of testing conducted to this point indicated that the adaptive bias would operate as intended with the SPN gyro.

3.5 FINAL TEST RESULTS

3.5.1 Vibration Testing

The modified EAR demonstration gyro was vibration tested to determine the maximum support capability. The vibration input was 40 Hz sinusoidal along each of the three support axes. The 40 Hz test frequency is the resonant frequency of the shock isolation system at the time of the specified EAR shock input. The test results are shown below:

Support Axes	Max. Support Capability
X	22.0 g peak
Y	21.0 g peak
Z	21.5 g peak

3.5.2 Drift Repeatability Testing

Followong the vibration testing a series of four drift tests were conducted with the EAR gyro to demonstrate drift repeatability. The configuration of the test gyro differed from the SPN gyro, as follows:

EAR Gyro Configuration	SPN Gyro Configuration
10 gram Isotropic beryllium rotor	10 gram I400 Beryllium rotor
0.0015" rotor to electrode gap	0.0018" rotor electrode gap
Bias Voltage = 473 Vrms	Bias Voltage = 262 Vrms
High Voltage transformer output = 5000V p-p	High Voltage transformer output = 4000V p-p

The drift repeatability tests consisted of runs 2602 through 2605. Run 2602 was the first test and was used to obtain calibration coefficients with which to predict the other three runs. The coefficients determined from run 2602 are as follows (all values are in milli-dyne-cm):

γ_{10} = 0.3545 γ_{20} = 4.9982

γ_{12} = 14.9647 γ_{21} = -14.9672

γ_{13} = 0.0743 γ_{22} = 0.7437

γ_{23} = -2.1580

The residual drift (nonrepeatability) for runs 2603 through 2605 are shown in Figures 3.5-1 through 3.5-3. A summary of the results of the drift repeatability tests are given in Table 3.5-1.

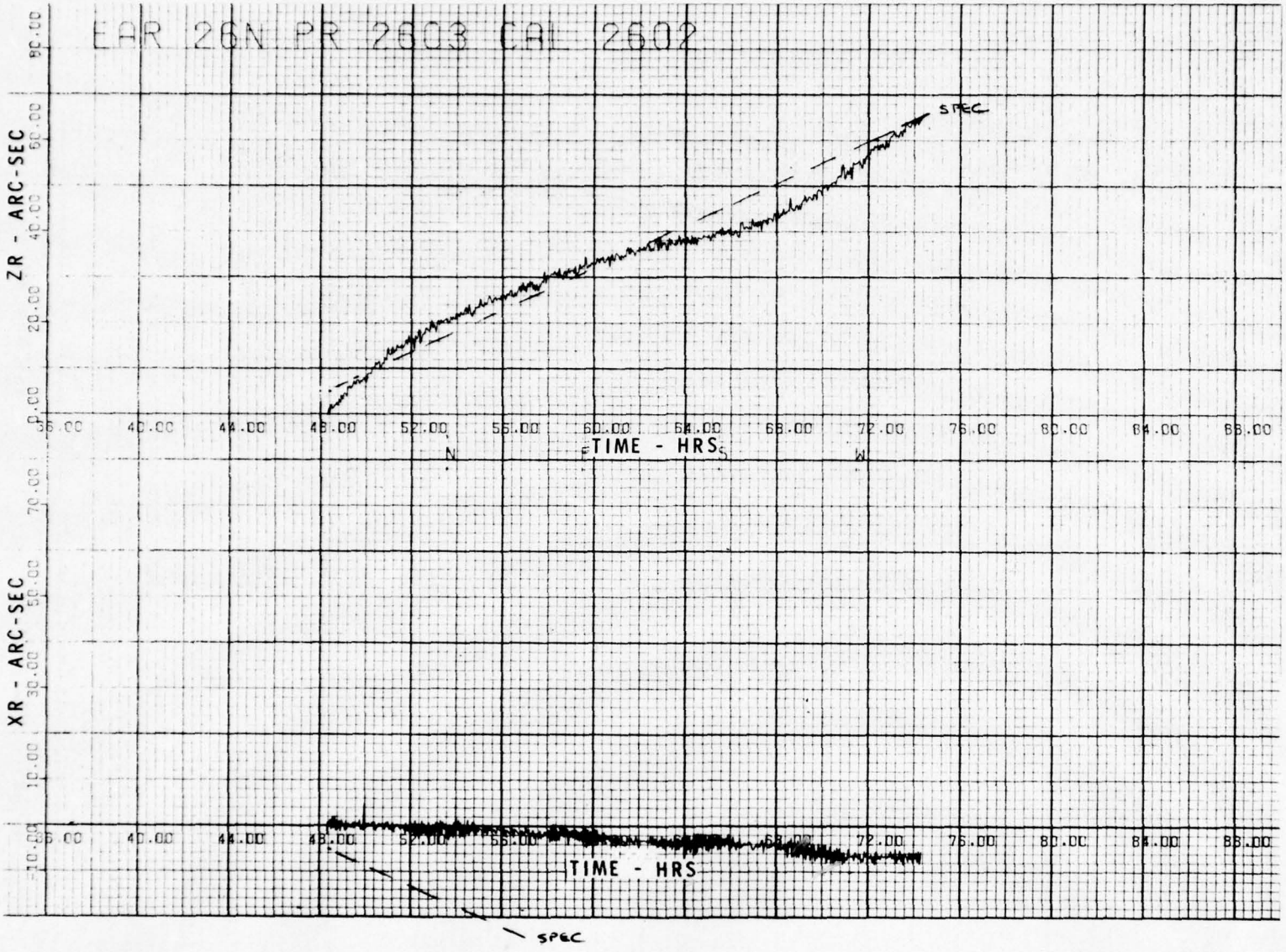


FIGURE 3.5-1. RUN 2603 RESIDUAL DRIFT

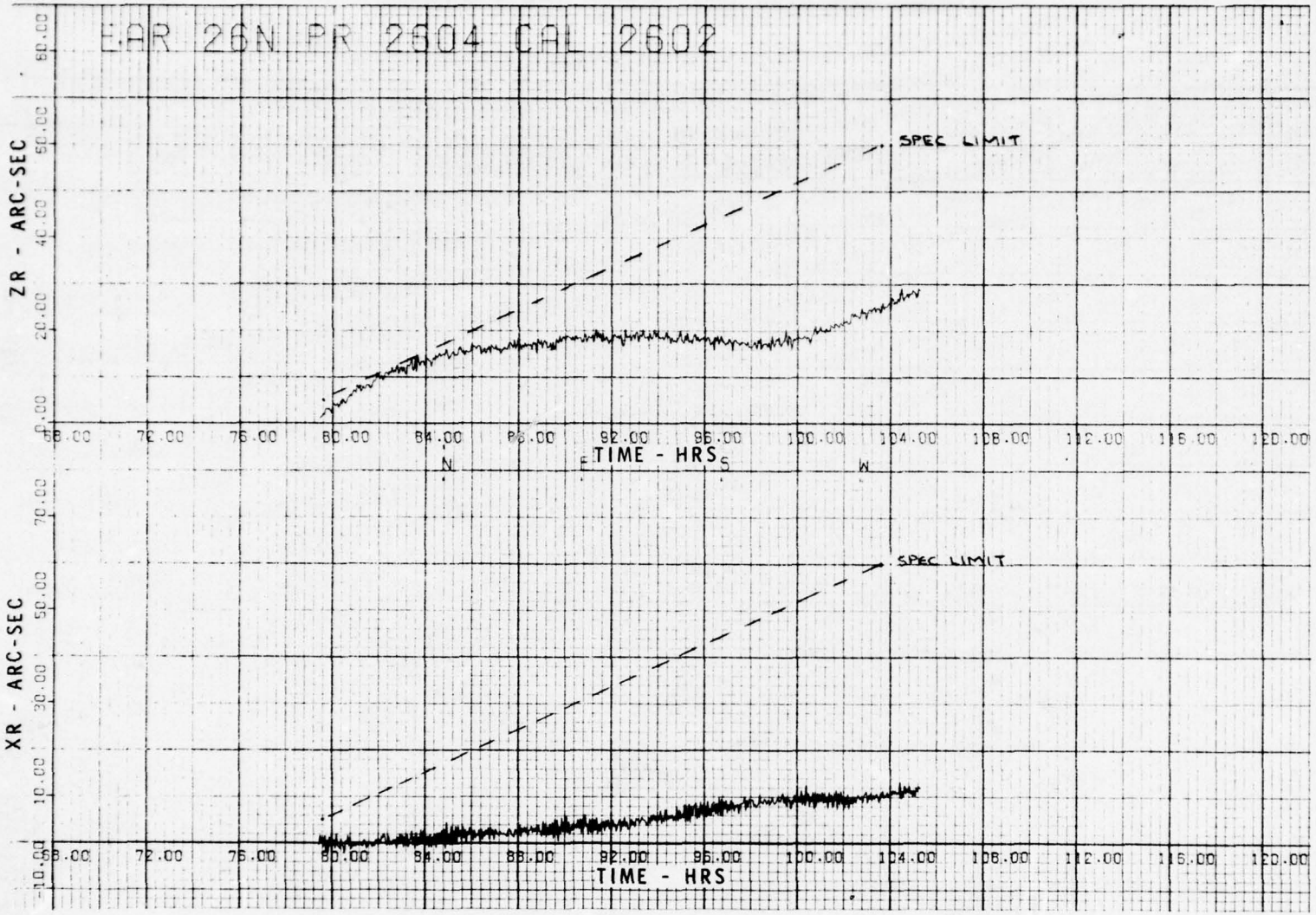


FIGURE 3.5-2. RUN 2604 RESIDUAL DRIFT

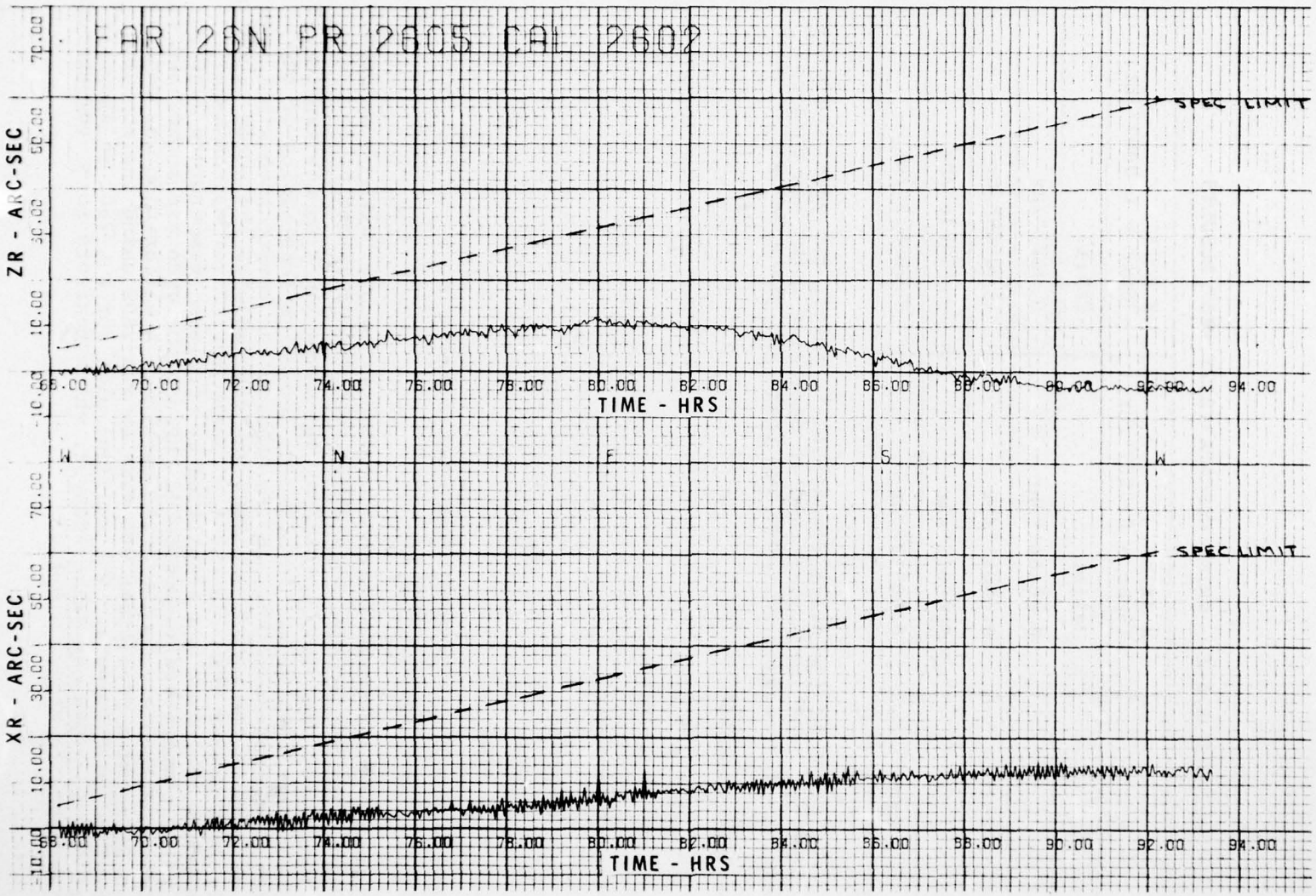


FIGURE 3.5-3. RUN 2605 RESIDUAL DRIFT

TABLE 3.5-1. DRIFT REPEATABILITY TEST RESULTS

Run	X axis (Spec = 0.0007°/hr)	Z axis (Spec = 0.0007°/hr)
2602	Calib.	Calib.
2603	0.000081°/hr	0.0007°/hr
2604	0.00011°/hr	0.00029°/hr
2605	0.00015°/hr	0.000046°/hr
RMS of 3 Runs	0.00017°/hr	0.000512°/hr

After completion of the drift repeatability tests, two additional tests (runs 2606 and 2607) were performed to determine rotor and envelope parameters. The results of these two tests are given below:

Envelope mismatch

X axis = 2.5 μin.

Y axis = 13.6 μin.

Rotor miscentering

X = 12 μin.

Y = 3 μin.

Z = 12 μin.

Rotor shape third harmonic component = 0.68 μ in.

Rotor optimum speed = 715 rps.

These parameters represent a good envelope assembly, with no apparent anomalies, and are typical of a SPN gyro envelope assembly.

As noted above, the rotor in the EAR demonstration gyro was fabricated from isotropic beryllium. In order to determine sensitivity of the rotor to temperature change, and to observe the temperature stabilization effects on the rotor, run 2602 was started with the rotor approximately 20°F hotter than the envelope assembly. After approximately seven hours the rotor had stabilized at operating temperature (180°F). The rotor temperature is monitored through the gyro gap sensor and is recorded continuously during drift testing. A calibration was made on run 2603 and a prediction was made on run 2602 using the run 2603 calibration coefficients. The residual plot for run 2602 is shown in Figure 3.5-4. (The gap sensor output, which monitors rotor temperature is also shown in Figure 3.5-4).

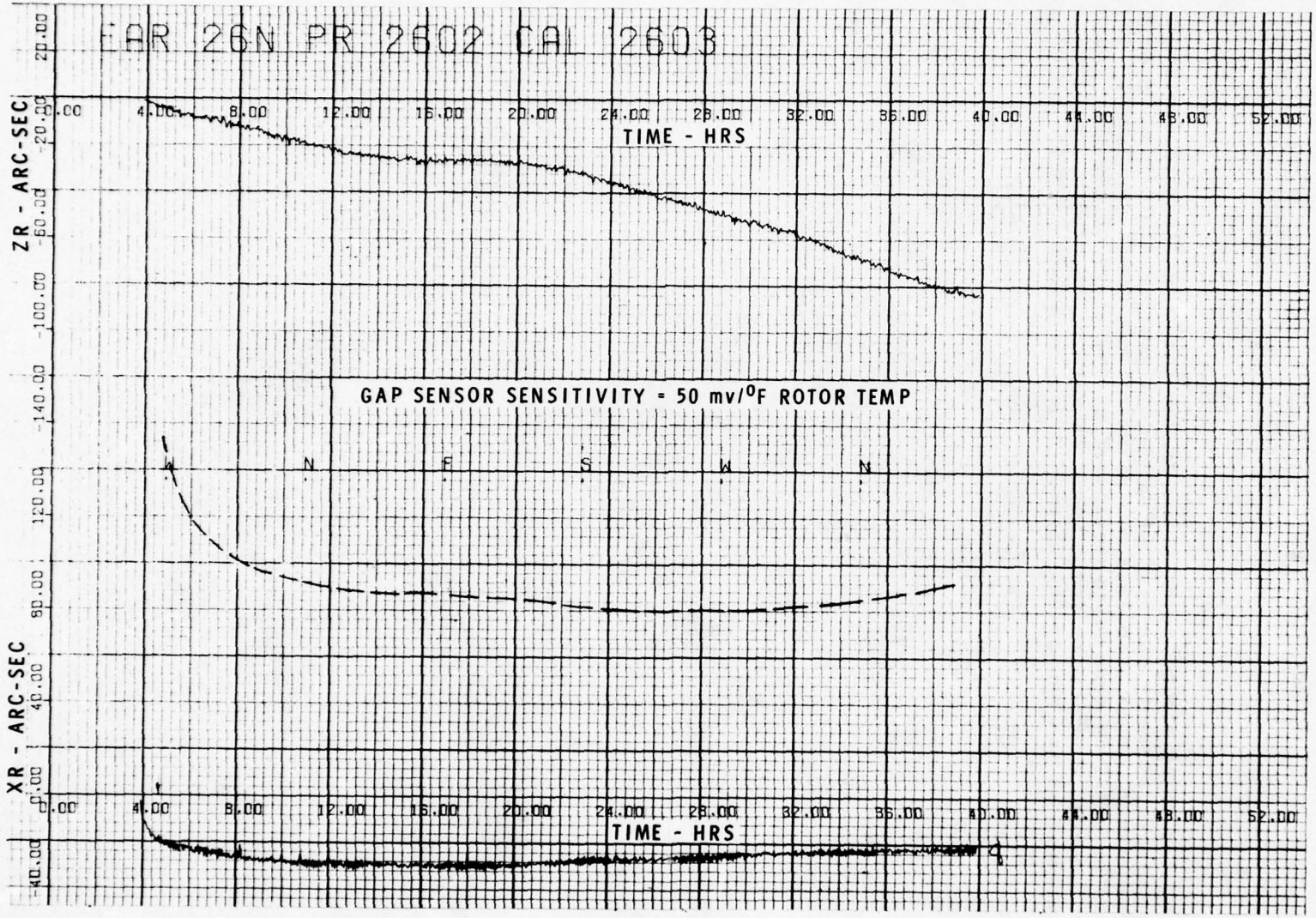


FIGURE 3.5-4. RUN 2602 RESIDUAL DRIFT

During the first six or seven hours of the run a small stabilization effect (approximately one-half of the specification limit) can be seen on the X axis. This stabilization is relatively small considering that the rotor was 20°F from being stabilized at the start of the run. During normal operation the gyro rotor would be within 2°F of its operating temperature at the end of the startup sequence (start of drift test).

Section 4

INCREASED ΔV RESOLUTION

After performing the initial mechanization tradeoffs and detailed circuit design, brassboards of the High Resolution Pulse Width Modulated (HRPWM) loop and the Hypha-Interpolator (H/I) were built and integrated with the SPN/GEANS accelerometer test station. The HRPWM was constructed so that it could be inserted in place of the SPN/GEANS rebalance electronics in the test station. The H/I was designed as an add-on to the SPN/GEANS loop with no modifications to that loop being required. All three configurations were then tested with the same accelerometer, precision voltage reference, frequency source, and test equipment.

The SPN/GEANS PWM loop was used as a basis for evaluating the station and the two high resolution loops. Considerable effort was put into evaluating and improving the test station using the SPN/GEANS loops. The resulting modifications to the station are summarized in Subsection 4.3. With the modifications installed, stability runs were made demonstrating 4 ppm stability with 1 g inputs to the accelerometer, and linearity tests showed nonlinearities comparable to those predicted for the accelerometer alone. Preliminary test results of the high resolution loops showed both to be functionally operational and both giving better resolution than the SPN/GEANS loops. Noise appeared to be keeping both loops from reaching their resolution limits.

When work was resumed on this contract, it was decided to construct a new brassboard. This consisted of a VMU casting in which a single accelerometer was mounted, along with all loop circuitry and reference circuits (Figures 4.0-1 through 4.0-5). The brassboard was so fabricated that the SPN/GEANS loop board could be removed and replaced with the HRPWM loop board. The voltage reference, precision clock, signal generator excitation, and torquer bridge remained common to both loops. A new control panel was fabricated to provide power control, signal monitoring, and data processing circuits. Detailed descriptions of both high resolution methods follow. Note that a second approach to the HRPWM method was mechanized after the initial one was evaluated.

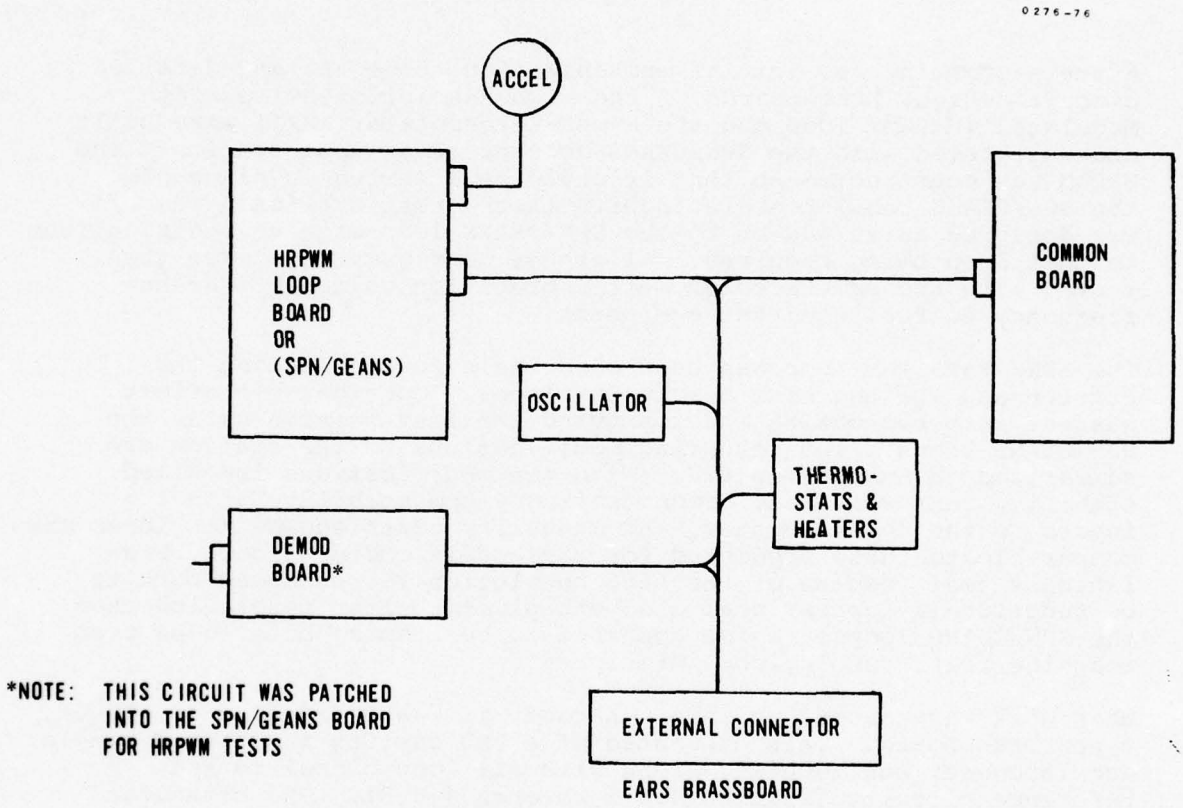


FIGURE 4.0-1. EARS BRASSBOARD

0276-73

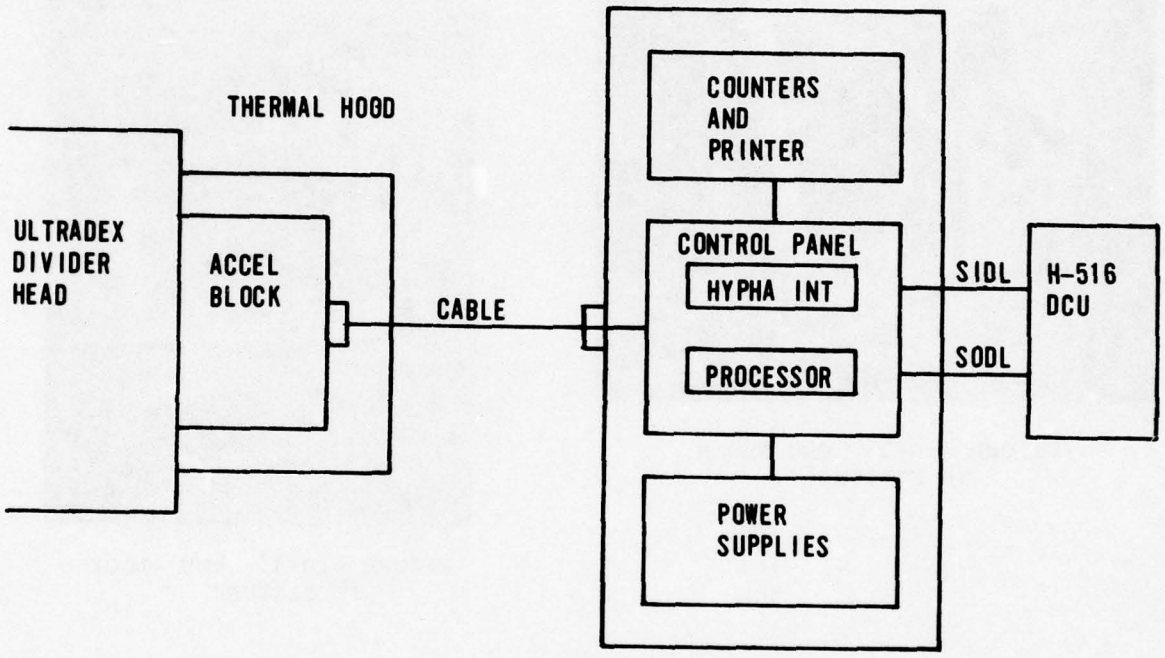


FIGURE 4.0-2. EARS BRASSBOARD TEST SETUP

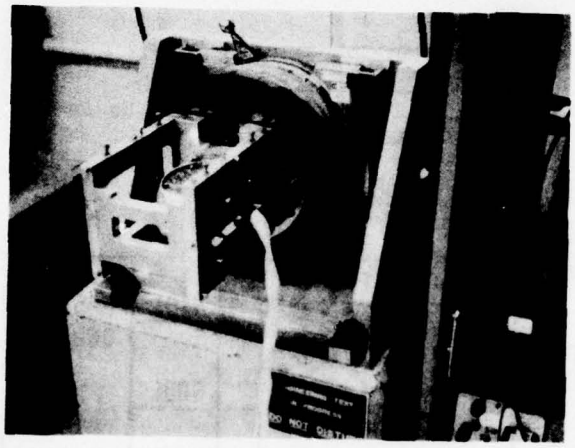


FIGURE 4.0-3. VMU BLOCK
IN FIXTURE

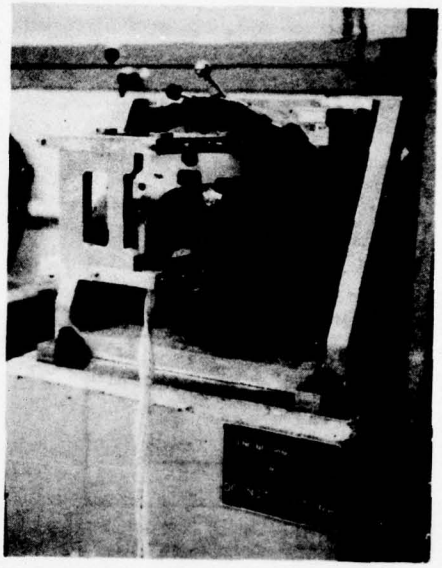


FIGURE 4.0-4. VMU BLOCK
IN FIXTURE

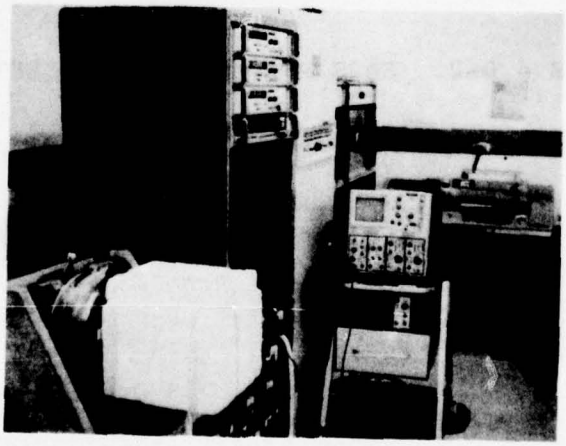


FIGURE 4.0-5. ACCEL LOOP TEST STAND

4.1 HIGH RESOLUTION PULSE WIDTH MODULATED ACCELEROMETER LOOP

For completeness, both approaches tested are discussed in this section.

4.1.1 Technical Circuit Description

4.1.1.1 First Approach

The original High Resolution Pulse Width Modulated (HRPWM) accelerometer loop block diagram is shown in Figure 4.1-1. This loop is patterned after the SPN/GEANS loop. The sensed pendulum displacement is first amplified and then demodulated to convert it to dc. This signal is then filtered and amplified and its amplitude compared to a sawtooth waveform.

The output of the comparator is a pulse width modulated signal whose duty cycle is proportional to the dc input. This signal is then clocked to provide incremental pulse width changes. This signal is encoded to provide the loop output signal and also drives the torquer bridge which in turn uses the signal as a current steering signal to rebalance the pendulum. Figure 4.1-2 shows how the pulse pattern is generated. For simplicity, it shows a pulse pattern that can be changed in four discrete steps, like SPN/GEANS.

If the dc level of the compensation amplifier output is limited to the level of the sawtooth within the boundary of the center dashed lines, the falling edge of the comparator output will occur between the dashed lines as shown on Line 1 of Figure 4.1-2. The torquing pulse output is shown on Line 2, equal plus and minus torquing time. Lines 3 and 4 shown the pulse patterns generated when the dc level is within the boundary of the dashed lines on the upper portion of the sawtooth slope. The resulting torquer pulse shows two more plus torquer time periods then minus. The bottom pulse patterns show two of the possible sixteen torquer waveforms in HRPWM.

Figure 4.1-3 shows a schematic of a single 0.00125 foot/second/pulse HRPWM loop. A crystal oscillator provides 2,097,152 Hz ±5 ppm which is used to generate the timing signals required. The 512 Hz signal is used to generate the triangular wave reference in the PWM accelerometer temperature control circuit. The 65,536 Hz signal is used to generate the accelerometer signal excitation and is used to demodulate the pendulum displacement signal. The 65,536 Hz signal for the signal generator is reclocked with the 131,072 Hz signal to produce a 90-degree phase shift. This phase shift combined with the 90-degree phase shift in the accelerometer produces the proper phase relationship for demodulating the pendulum displacement signal.

In this loop, the dither frequency is 16,384 Hz. It is a square wave of this frequency whose duty cycle is varied (pulse width modultated). The four binary frequencies, from 16,384 Hz to 131,072 Hz go to a six bit D/A converter which is used to generate the stepped sawtooth PWM reference. The D/A output increases in 0.64 volt steps from -5.12 volts to +5.12 volts. The center step is double amplitude to linearize

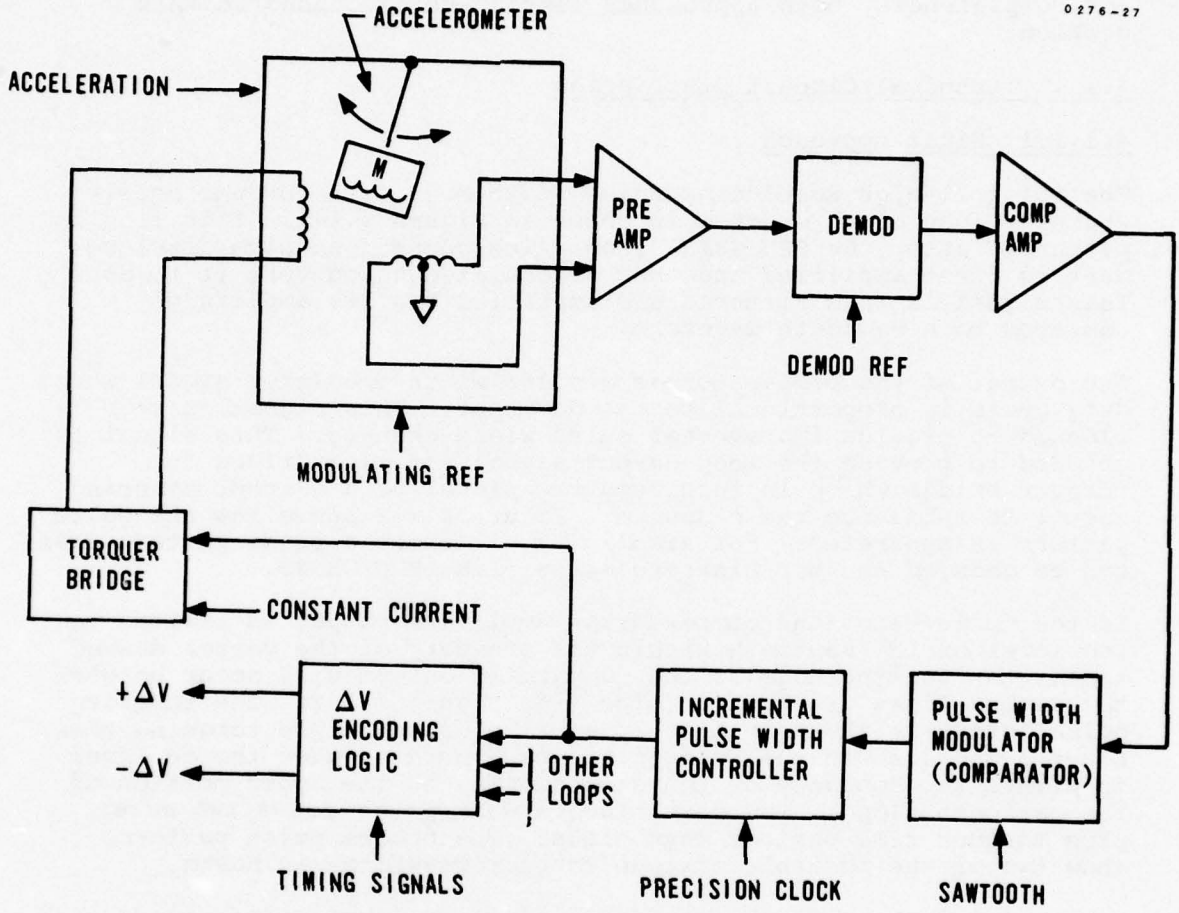


FIGURE 4.1-1. PULSE WIDTH MODULATED ACCELEROMETER LOOP

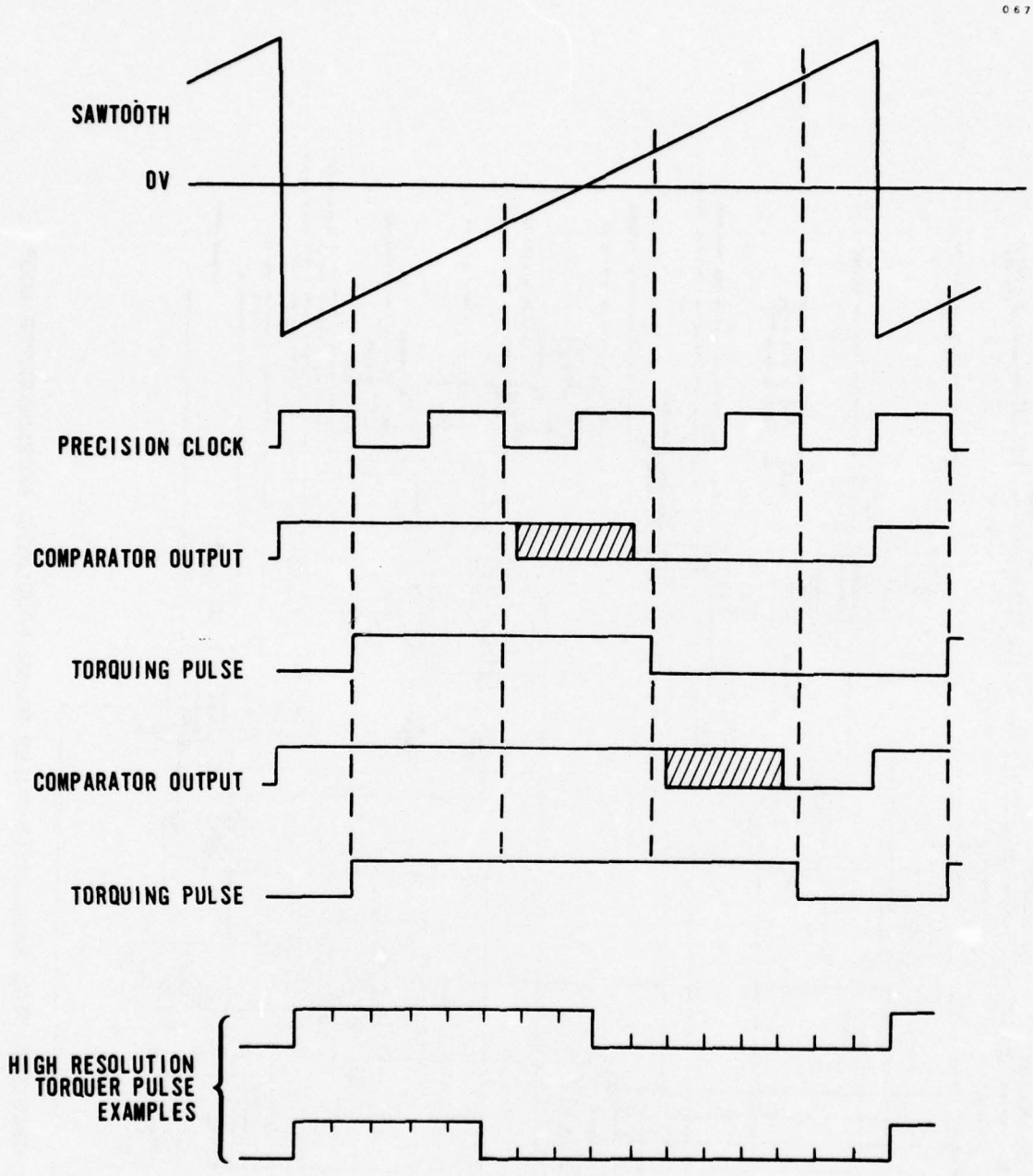


FIGURE 4.1-2. INCREMENTAL PULSE WIDTH MODULATION

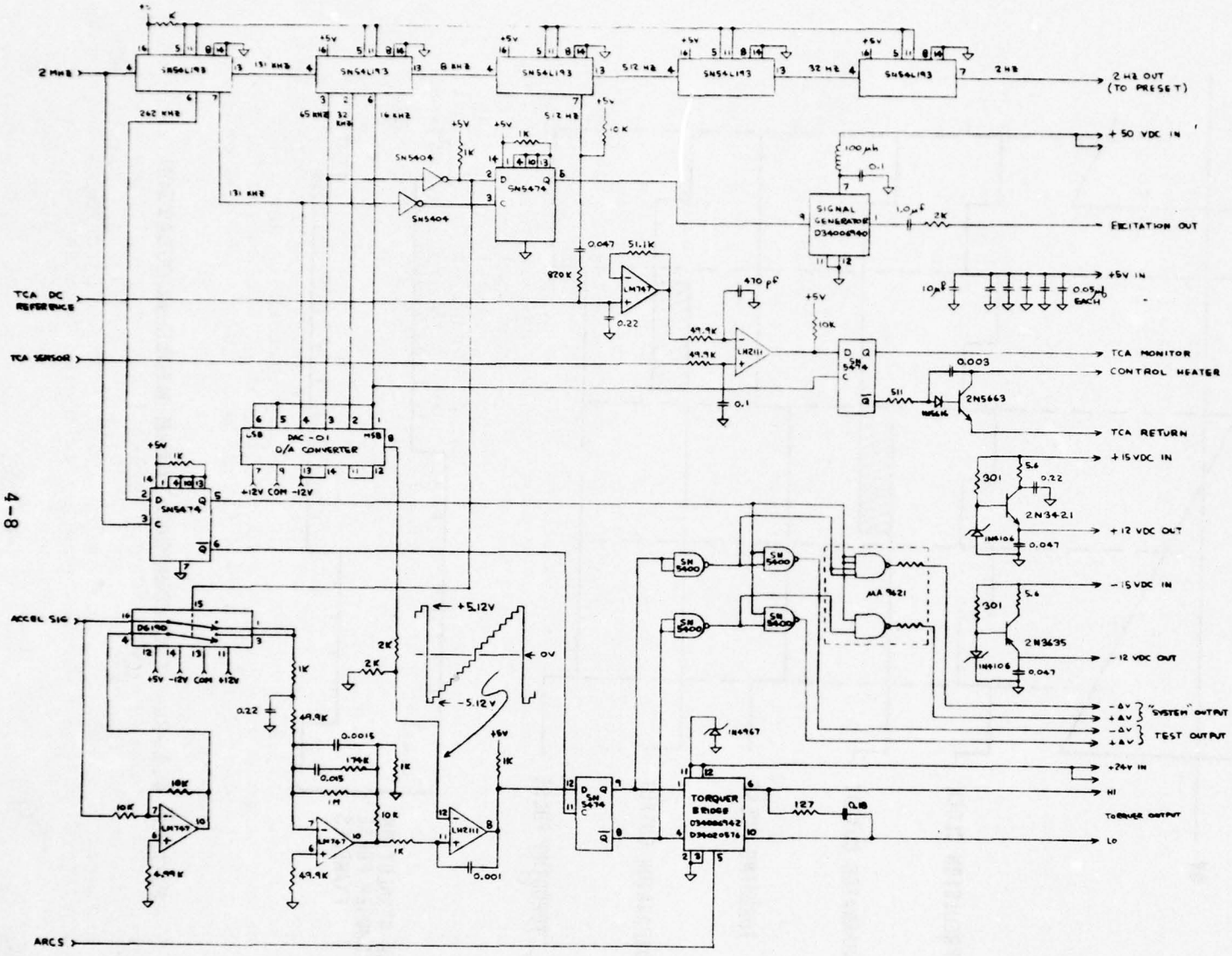


FIGURE 4.1-3. ORIGINAL HIGH RESOLUTION PULSE WIDTH MODULATED ACCELEROMETER LOOP

the gain. The steps occur at a 262,144 Hz rate (16 steps/cycle) and the cycle rate is 16,384 Hz.

The 262,144 Hz signal is used to clock the 16,384 Hz pulse width modulated waveform so that its width is precisely known. The 262,144 Hz signal is first reclocked with 2,097,152 Hz to give it the stability of the oscillator reference.

All of the electronics described to this point are common; that is, shared by all three loops in a system configuration.

The pendulum displacement signal, a 65,536 suppressed carrier waveform, comes into a demodulator and is multiplied (the gain is one) by the 65,536 Hz demodulator reference signal. The output of the demodulator goes through a low pass amplifier stage which provides loop gain, compensation, and filtering. The dc level of the analog signal is compared to the 16,384 Hz stepped sawtooth waveform.

The output of the comparator is a 16,384 Hz pulse width modulated waveform, whose duty cycle is varied as a function of which step of the sawtooth the analog signal crosses (where the analog amplitude equals the amplitude of the stepped sawtooth).

This signal is then precision clocked with the 262,144 Hz signal. Timing wise, this clock occurs at the center of each sawtooth step. This output is pulse width controlled in 16 discrete steps.

The signal then goes to the torquer bridge which supplies plus or minus current to the accelerometer torquer as a function of the state of the flip-flop output. The current supplied by the torquer bridge is precisely controlled by a constant supply. The HRPWM accelerometer loop as mechanized has an open loop transfer function as shown in Figure 4.1-4. The compensation amplifier in the loop introduces a lag at 50 rads/sec (8.3 Hz), a lead at 400 rads/sec (67 Hz), and a double lag for high frequency filtering at 5,000 rads/sec (822 Hz). The dc gain of the compensation amplifier is 200, yielding a unity gain crossover, bandwidth of 2,000 rads/sec (333 Hz). This is twice the bandwidth of SPN/GEANS loop.

4.1.1.2 Final Approach

Initial testing on the original HRPWM loop showed that the count scatter and noise were of an unacceptable level (see Paragraph 4.1.3.1). Another approach was then implemented as described below. Figure 4.1-5 shows a block diagram of the second HRPWM configuration. This loop is a simple modification of the existing SPN/GEANS loop.

The dither frequency of this loop remains at the 2,048 Hz level of SPN/GEANS, with only the torquer pulse increments being made smaller by the use of faster clocking. Also, a new demodulator circuit was designed to reduce the loop noise level. The original SPN demod was a multiplier which was replaced by switching type device. See

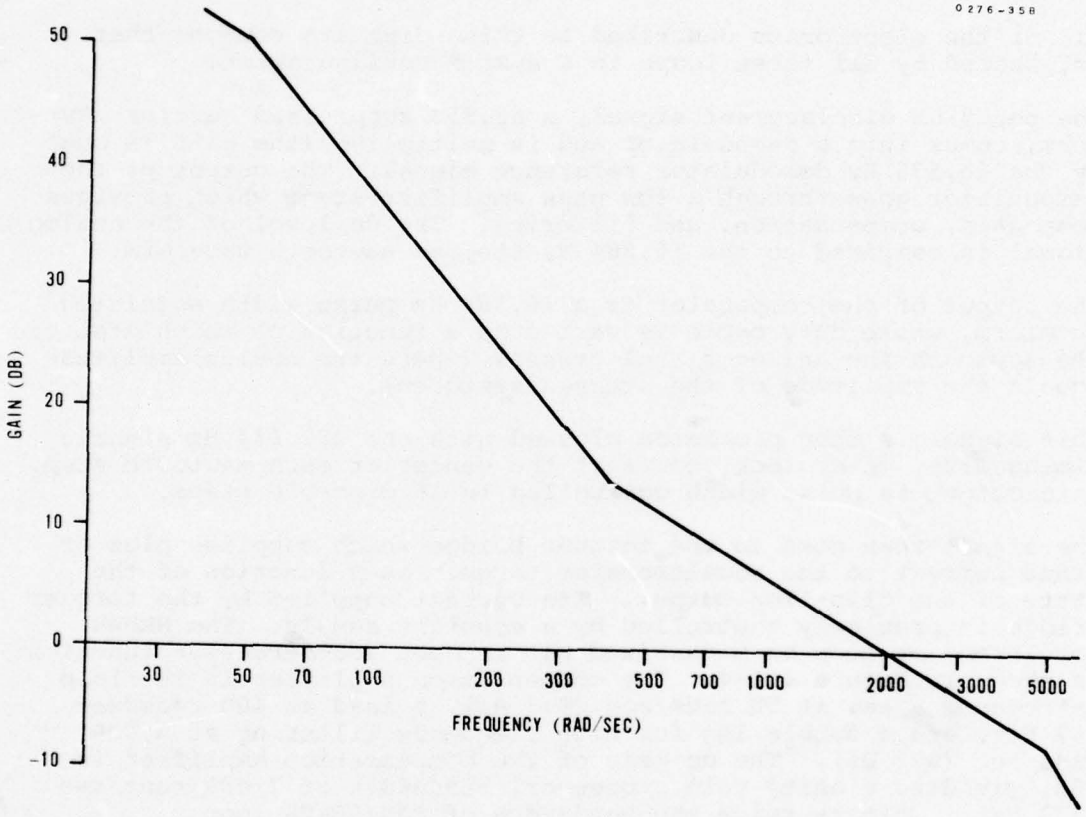


FIGURE 4.1-4. HRPWM OPEN LOOP TRANSFER FUNCTION

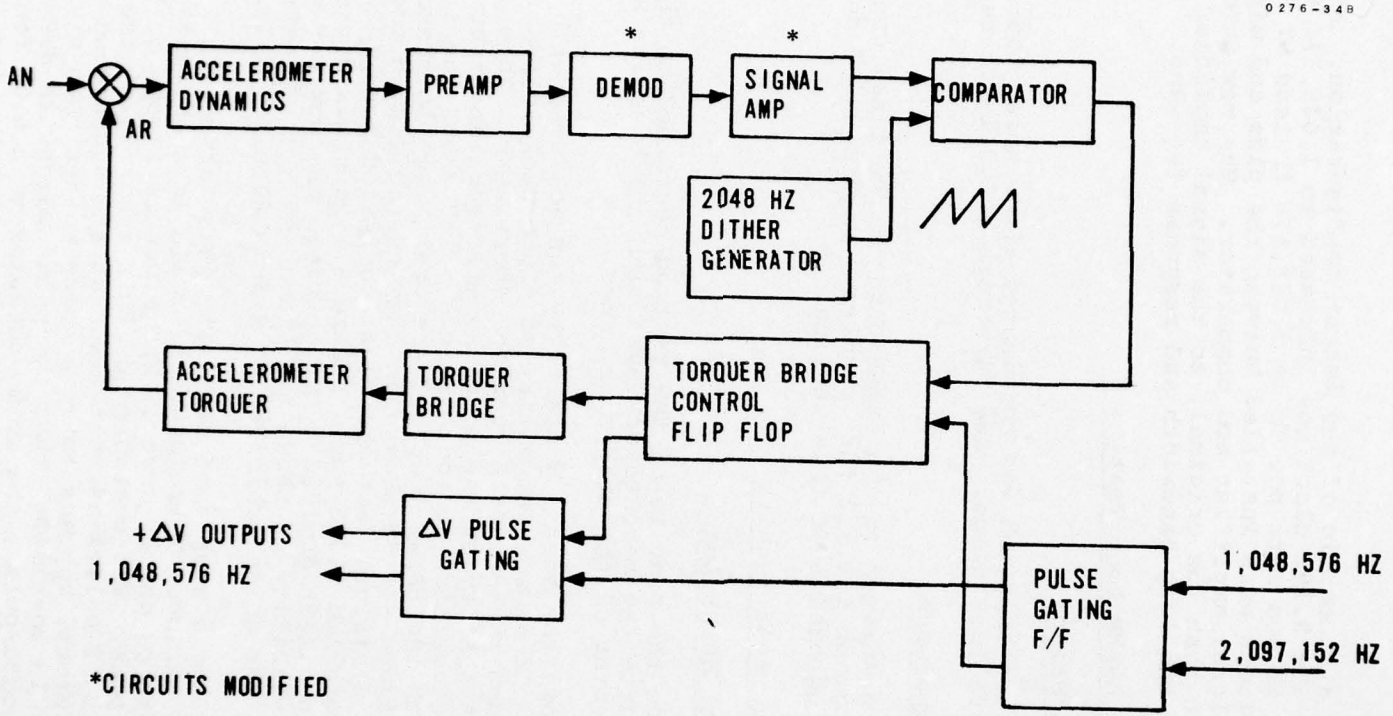


FIGURE 4.1-5. HRPWM LOOP BLOCK DIAGRAM

Figure 4.1-6 for a schematic of the latest configuration. As seen in Figure 4.1-6, the 8,192 clock was increased to 1,048,576 Hz, which causes the ΔV sum rate now to be 1,048,576 instead of 8,192. Decoupling capacitors were installed between the plus and minus 12 volt sources at the signal amplifier and comparator. The new demodulator has a higher gain than the original, so the signal amplifier gain was adjusted to keep the loop bandwidth and response the same.

4.1.2 Status of HRPWM Loop Testing

4.1.2.1 First Approach

The testing on this approach was terminated after noise testing on the new brassboard took place. See Paragraph 4.1.3.1 for reasons.

4.1.2.2 Final Approach

All testing was completed on the brassboard of the final configuration. See Paragraph 4.1.3.2 for results. Figure 4.1-7 shows the chronological progression of this testing.

4.1.3 Brassboard Test Results

4.1.3.1 Original HRPWM Loop

The following are the results of the testing performed on the HRPWM loop as compared to the results achieved with the baseline SPN/GEANS loop up to the point of the stop work order.

Figure 4.1-8 shows the best 1 g stability run achieved with the SPN/GEANS loop. It shows a stability of 6 ppm peak-to-peak over 65 hours and 4 ppm peak-to-peak over the short term. This plot also shows the stability of the accelerometer rebalance current supply over the same time period. Figure 4.1-9 shows the stability run achieved with the HRPWM loop. There are three plots shown in this figure. Figure 4.1-9b shows raw data counts scaled one ΔV pulse per minor division. For the counting period used (800 seconds) each pulse is weighted 0.048 ppm. Figure 4.1-9a shows a plot of the same data in 4.1-9b divided by 20 to yield one ppm per minor division. The stability as shown by both a and b is 2 ppm peak-to-peak. However, the noise exhibited in 4.1-9b must be analyzed.

Figure 4.1-9c shows a sample of stability data taken with a 40-second counting period. Therefore, the scale is such that one minor division is 1 ppm or one ΔV count. The error is 24 ppm or 24 ΔV pulses peak-to-peak. The character of this error is of the same order in numbers of pulses as that taken at the 800-second sample rate. It, therefore, appears to be a noise rather than stability problem. If it is considered that the pulse weight in HRPWM is 0.00125 foot/second/pulse, the noise computes to a 0.03 foot/second peak-to-peak error in velocity change. This is below the 0.08 foot/second quantization (2 net pulse resolution) capability of the SPN/GEANS loop.

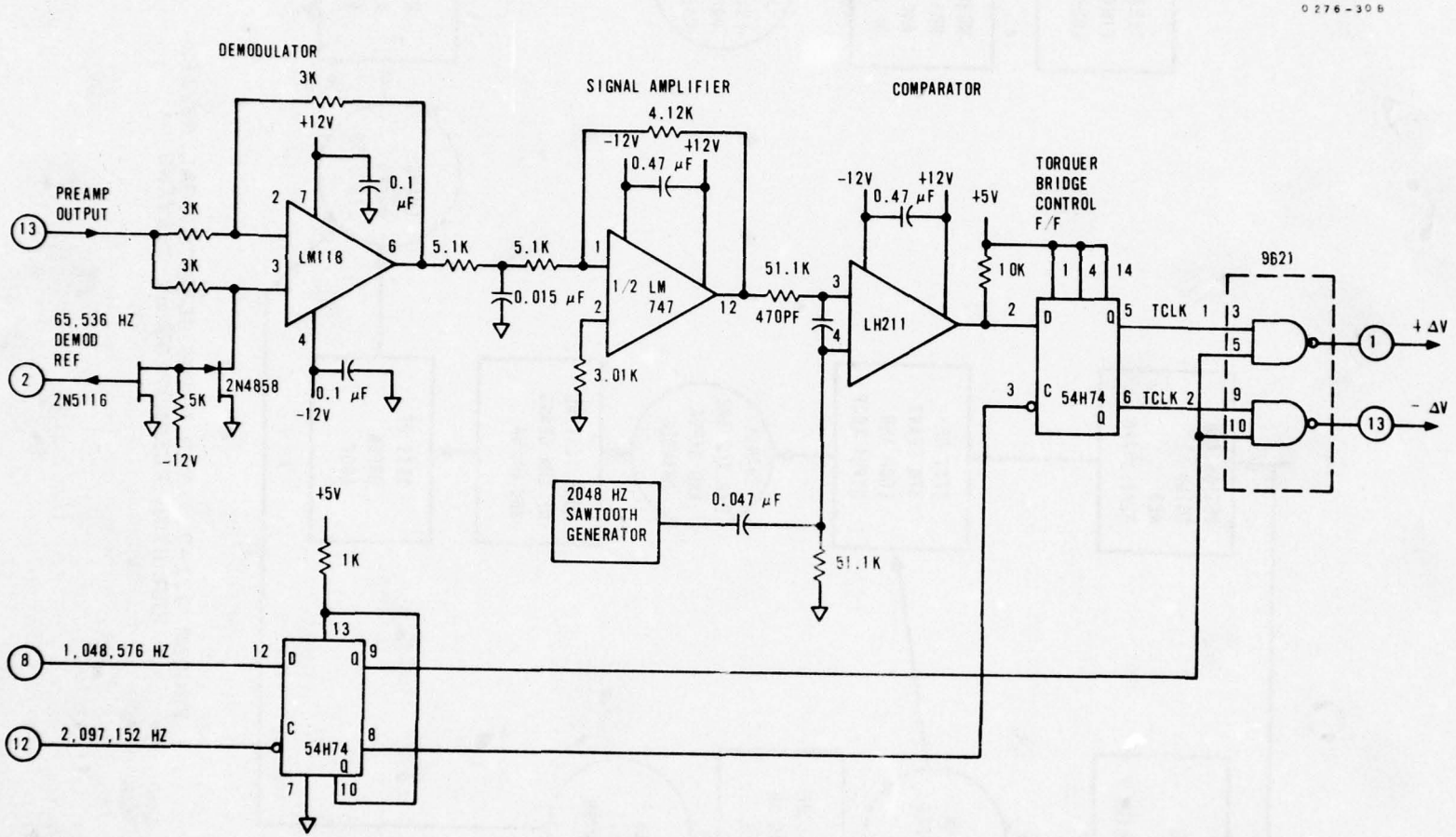


FIGURE 4.1-6. HRPWM LOOP FORWARD LOOP ELECTRONICS

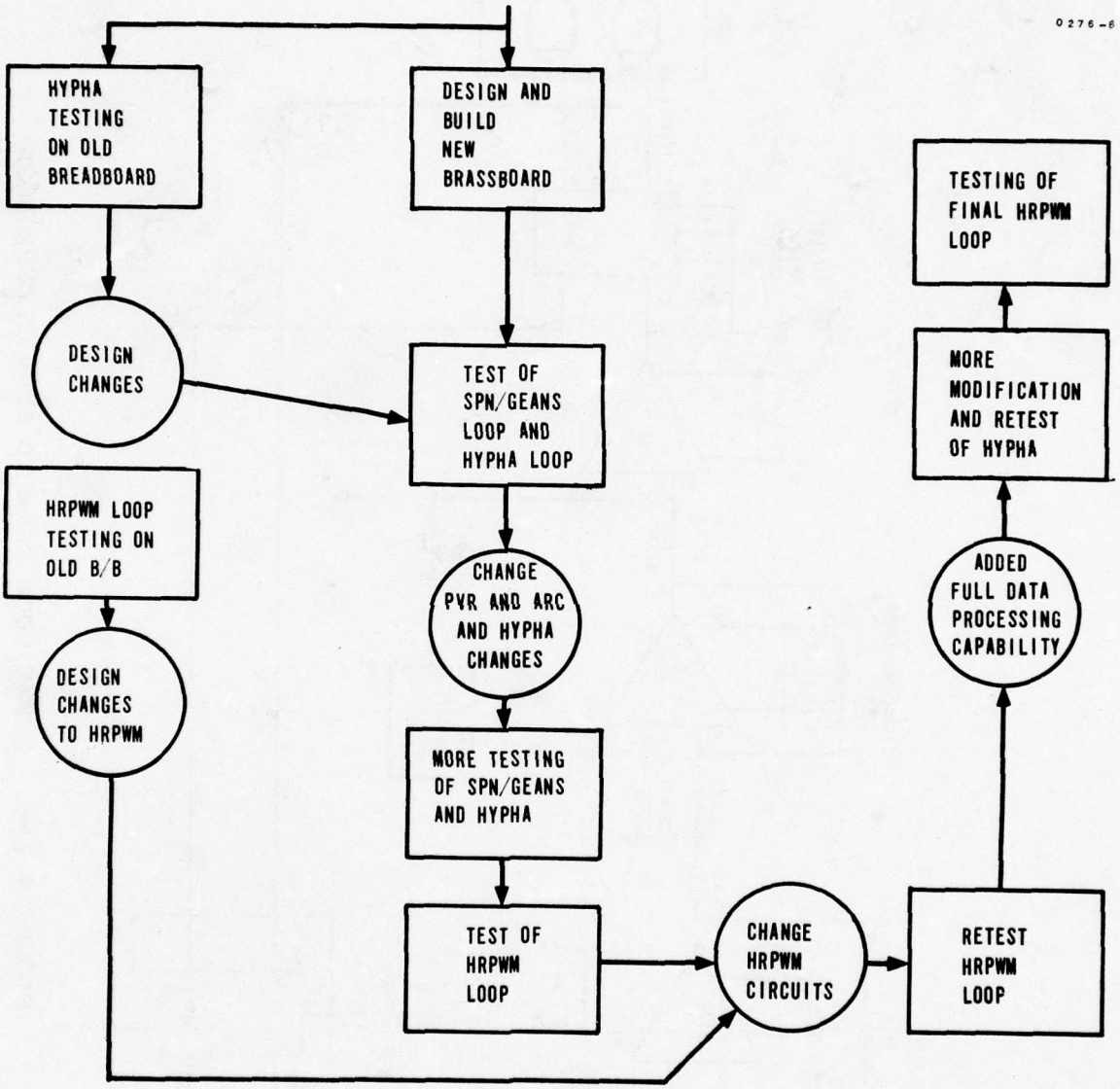


FIGURE 4.1-7. EAR PROGRAM TECHNICAL REVIEW
EAR HIGH RESOLUTION ΔV TESTING

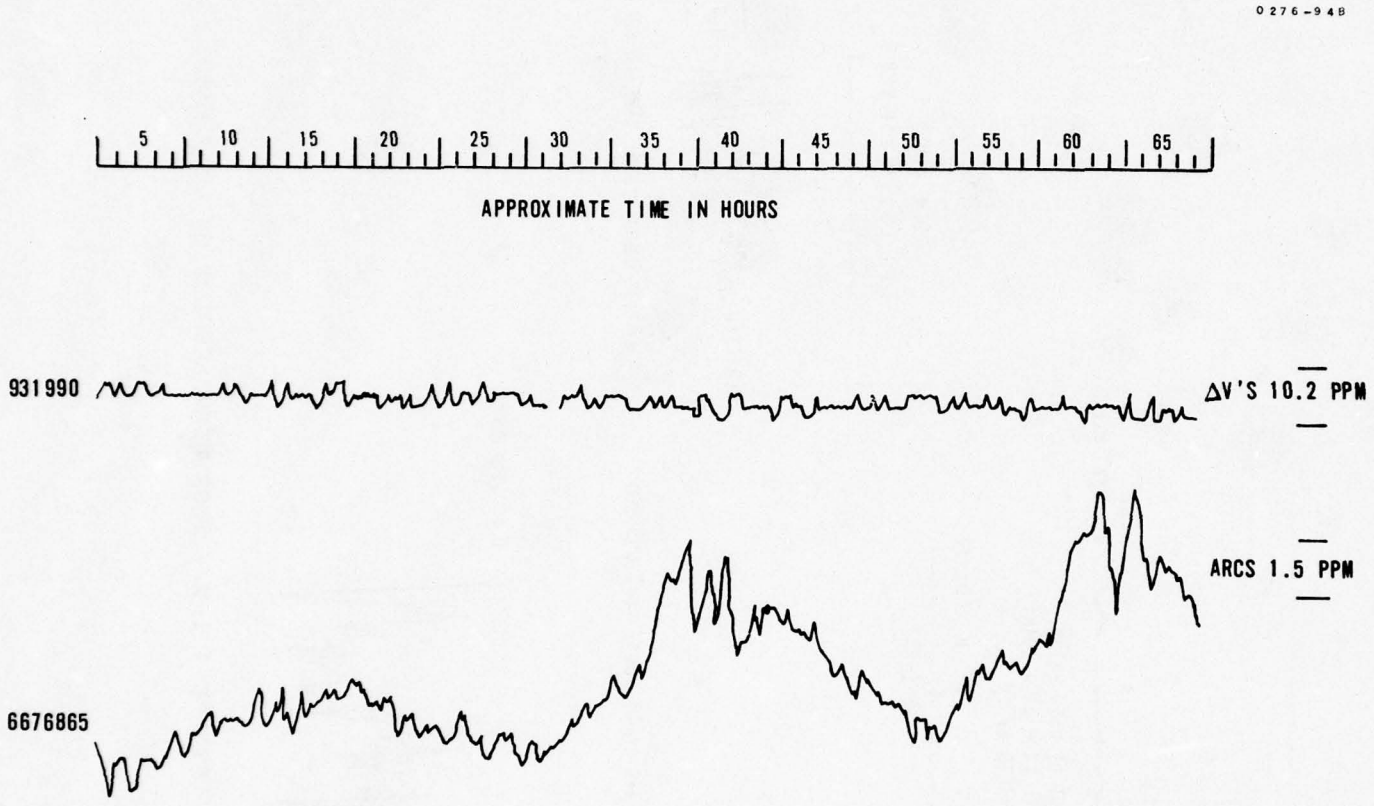


FIGURE 4.1-8. BEST 1g STABILITY RUN

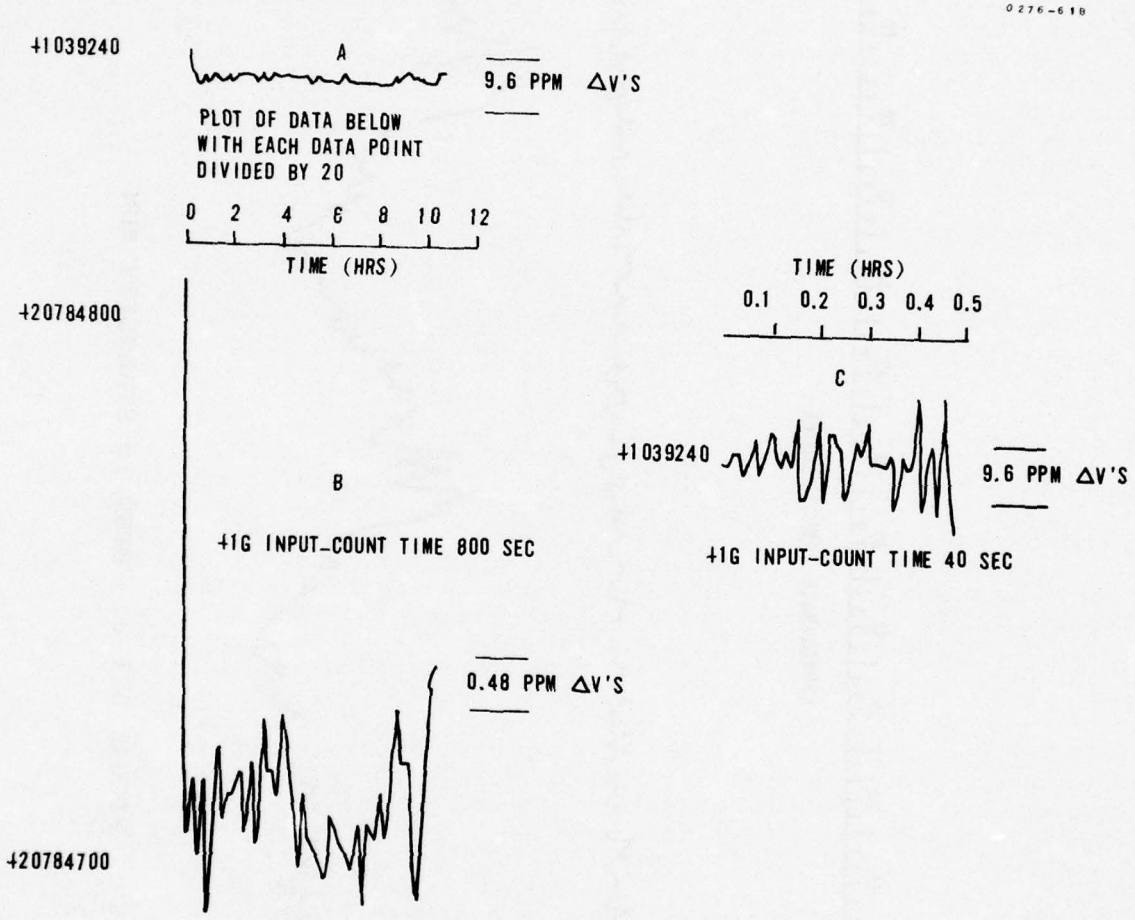


FIGURE 4.1-9. EARS HIGH RESOLUTION LOOP DATA

Figure 4.1-10 shows the best SPN/GEANS full linearity run. It has an 82 ppm peak-to-peak error and a 48 ppm rms deviation from ideal. Figure 4.1-11 shows the HRPWM full linearity run. It has a 55 ppm peak-to-peak error and a 27 ppm rms deviation from ideal. This depicts a linearity improvement of HRPWM over SPN/GEANS. These figures also include the resultant errors with the g^2 dependent errors removed. The resultant SPN/GEANS error was 16 ppm rms deviation and the resultant HRPWM error was 18.5 ppm rms deviation. Both improved beyond the linear fit. On the four-point linearity tests, SPN/GEANS runs ranged from 68 to 112 ppm peak-to-peak. The HRPWM loop ranged from 55 to 60 ppm peak-to-peak.

Figure 4.1-12 shows a null deadband run on the SPN/GEANS loop. The deadband is four arc seconds. This test was not run on the HRPWM loop.

Following the resumption of effort, the first configuration was mechanized in the new brassboard. The initial stability test of the SPN/GEANS baseline loop in the brassboard is shown in Figure 4.1-13.

A linearity test and null deadband test were also performed. The linearity test data is found in Figure 4.1-14 and null deadband in Figure 4.1-15. A five-day stability test was then performed. The data from this test is shown in Table 4.1-1. The simulated higher g testing originally called for in the test plan was attempted but not continued. It was observed that simulating higher g's by reducing the voltage reference and increasing the loop gain, while it does simulate higher g's, also increases loop noise proportionally. This noise then made invalid all attempts at evaluating higher resolution data.

Following baseline loop tests; the new HRPWM brassboard (in the original design) was tested. Figures 4.1-16 through 4.1-17 show the data collected. (The new computer data collecting and processing system was used to collect data samples. See Figure 4.1-18.) Table 4.1-2 explains the data format.

The stability counts were not good. The linearity test data shown in Figure 4.1-17 also indicate poor performance. Figure 4.1-18 shows typical data samples taken at a 256 Hz rate. It is seen that the average count deviation is approximately 1.5 counts. In the light of these tests results, compared with the Hypha data, further testing on the HRPWM loop was terminated and concentration was placed on the Hypha mechanization.

4.1.3.2 Test Results Final HRPWM

Following the completion of testing on the Hypha interpolator, it was decided to make further noise investigations of the SPN/GEANS loop to aid in developing a new HRPWM approach. Since the requirement for the count deviation was 0.7 count over a four-second sample at a 256 Hz rate, the following ground rules were established to define the technique to achieve the necessary pulse weight.

DEVIATION FROM LINEARITY + - 1G LINE 9-9-74
1G LINEARITY TEST PER REVISED TEST PLAN
LE172 DIVIDING HEAD USED 300. SEC COUNT TIME

DIV HEAD ANGLE DEGREES	DELTA V.S COUNTS/ 300 SEC	I.A. ANGLE DEGREES	G INPUT MICRO G'S	ACCEL INPUT MICRO G'S	ACCL INPUT-BIAS MICRO G'S	DEV FROM LIN MICRO G'S
0.0000	242830.0000	-89.9986	-999999.8750	-999853.0000	-1000000.1250	-0.2500
37.0000	193952.0000	-53.0014	-798650.1250	-798547.2500	-798654.3750	-4.2500
53.0000	146138.0000	-37.0014	-601834.5000	-601747.5000	-601854.6250	-20.1250
67.0000	94680.0000	-23.0014	-390753.5625	-390684.1875	-390791.2500	-57.6875
79.0000	46332.0000	-11.0014	-190833.0000	-190779.7187	-190886.7812	-53.7813
90.0000	0.0000	-0.0014	-24.5011	0.0000	-107.0093	-82.5082
101.0000	-46336.0000	10.9986	190784.9062	190796.1875	190689.1250	-95.7813
113.0000	-94896.0000	22.9986	390708.4375	390750.0625	390643.0000	-65.4375
127.0000	-146164.0000	36.9986	601795.3750	601854.6250	601747.5000	-47.8750
143.0000	-193970.0000	52.9986	798620.7500	798703.7500	798596.6250	-24.1250
160.0000	-242882.0000	89.9986	999999.8750	1000107.0000	999999.8750	0.0000
217.0000	-193982.0000	53.0014	798650.1250	798753.1250	798646.0000	-4.1250
233.0000	-146176.0000	37.0014	601834.5000	601904.0000	601796.8750	-37.6250
247.0000	-94908.0000	23.0014	390753.5625	390799.4375	390692.3750	-61.1875
259.0000	-46354.0000	11.0014	190833.0000	190870.3125	190763.2500	-69.7500
270.0000	-12.0000	0.0014	24.5011	49.4120	-57.6473	-82.1484
281.0000	46316.0000	-10.9986	-190784.9062	-190713.8125	-190820.8750	-35.9688
293.0000	94864.0000	-22.9986	-390708.4375	-390618.3125	-390725.3750	-16.9375
307.0000	146126.0000	-36.9986	-601795.3750	-601698.1250	-601805.2500	-9.8750
323.0000	193924.0000	-52.9986	-798620.7500	-798514.3750	-798621.5000	-0.7500

********** LINEAR VERSION **********

FIGURE 4.1-10. SPN/GEANS FULL LINEARITY RUN

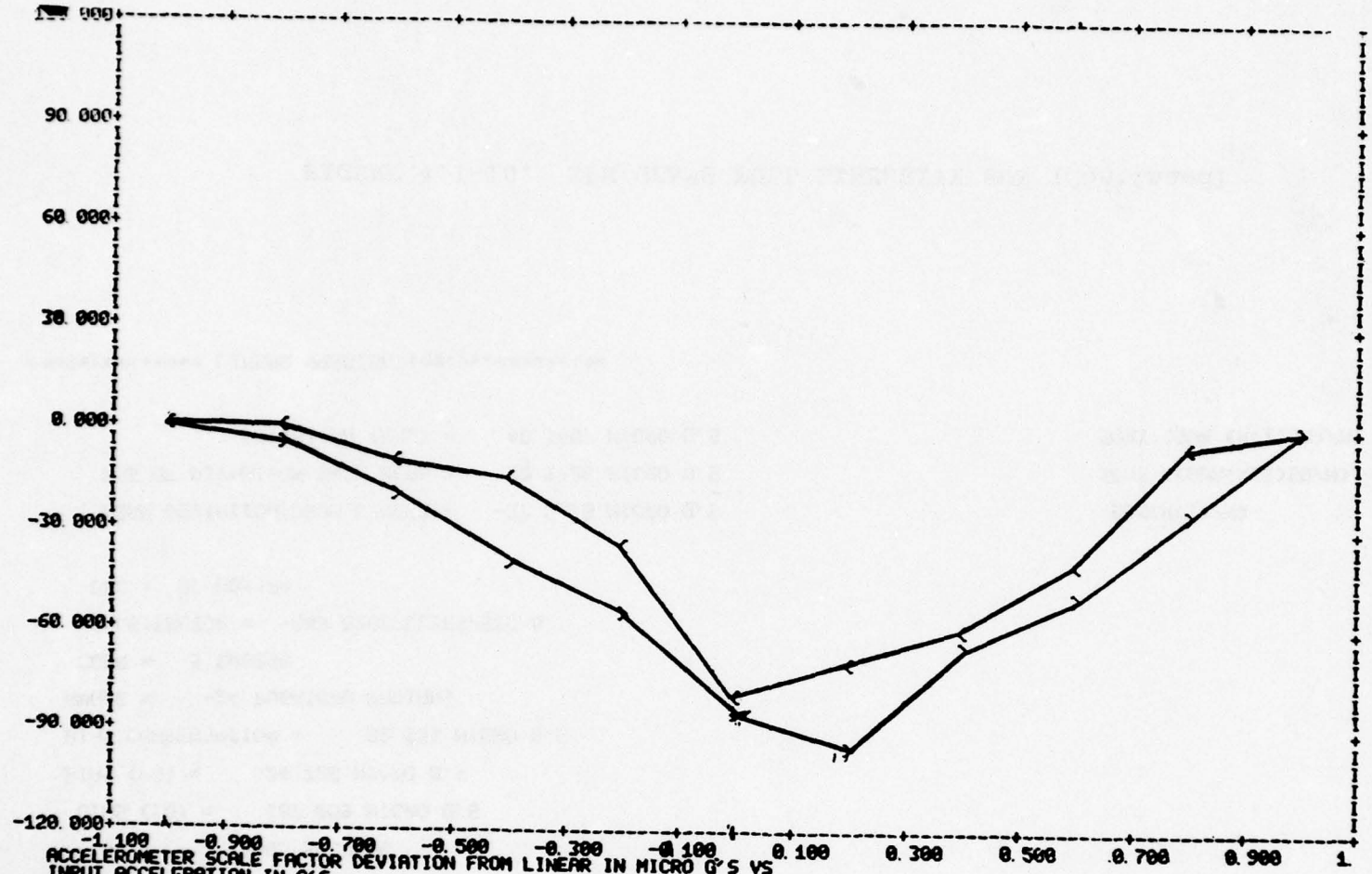


FIGURE 4.1-10. SPN/GEANS FULL LINEARITY RUN (Continued)

```
 POS1 =          0.
 POS2 =    -242882.
 POS3 =        -12.
 POS4 =     242830.
   DT =        300. SECONDS
 BIAS (1G) =     107.059 MICRO G,S
BIAS (0G) =      24.706 MICRO G,S
BIAS COMPENSATION =      82.353 MICRO G,S
ANGLE =     -24.706MICRO RADIANS
 CORR =    1.000000
 SCALE FACTOR =   -809.5200PULSES/SEC/G
  DHC =  90.001404

  MEAN DEVIATION FROM LINEAR =    -37.5119 MICRO G,S      SUM(X(I)/N)
  RMS OF DEVIATION FROM MEAN =     38.1726 MICRO G,S      SQRT ((SUM(X(I)SQ/N) - (MEAN)SQ)
          DEVIATION (RMS) =        48.1407 MICRO G,S      SQRT (SUM (X(I)SQ)/N)

************** LINEAR VERSION ****************
```

FIGURE 4.1-10. SPN/GEARS FULL LINEARITY RUN (Continued)

DEVIATION FROM LINEARITY + - 1G LINE 9-9-74
1G LINEARITY TEST PER REVISED TEST PLAN
LET'S2 DIVIDING HEAD USED 360. SEC COUNT TIME

DIV HEAD ANGLE DEGREES	DELTA V.S COUNTS/ 30U SEC	I.A. ANGLE DEGREES	G INPUT MICRO G'S	ACCEL INPUT MICRO G'S	ACCEL INPUT BIAS MICRO G'S	DEV FROM LIN MICRO G'S
0.0000	242800.0000	-89.9986	-999999.8750	-999937.6000	-1000000.1750	-0.3500
37.0000	193932.0000	-53.0014	-798650.1250	-798547.2500	-798647.7000	12.4250
53.0000	146138.0000	-37.0014	-601834.5000	-601747.4000	-601821.0750	12.6250
67.0000	94886.0000	-23.0014	-390753.5625	-390684.1875	-390741.1250	12.4375
79.0000	46332.0000	-11.0014	-190833.0000	-190779.7187	-190820.1562	12.8438
90.0000	0.0000	-0.0014	-24.5011	0.0000	-24.7069	-0.2069
101.0000	-46336.0000	10.9986	190784.9062	190726.1875	190755.7500	-29.1563
113.0000	-94890.0000	22.9986	390708.4375	390750.0625	390693.1250	-15.3125
127.0000	-146164.0000	36.9986	601795.3750	601854.6250	601780.2500	-15.1250
143.0000	-193970.0000	52.9986	798620.7500	798703.7500	798613.2500	-7.5000
180.0000	-242882.0000	89.9986	999999.8750	1000107.0000	999999.8750	0.0000
217.0000	-193982.0000	53.0014	798650.1250	798753.1250	798662.6250	12.5000
233.0000	-146176.0000	37.0014	601834.5000	601904.0000	601829.6250	-4.8750
247.0000	-94908.0000	23.0014	390753.5625	390799.4375	390742.5000	-11.0625
259.0000	-46354.0000	11.0014	190833.0000	190870.3125	190829.8750	-3.1250
270.0000	-12.0000	0.0014	24.5011	49.4120	24.7040	0.2029
281.0000	46316.0000	-10.9986	-190784.9062	-190713.8125	-190754.2500	30.6563
293.0000	94864.0000	-22.9986	-390708.4375	-390610.3125	-390675.2500	33.1875
307.0000	146126.0000	-36.9986	-601795.3750	-601698.1250	-601772.5000	22.8750
323.0000	193924.0000	-52.9986	-798620.7500	-798514.3750	-798604.8750	15.8750

********** G**2 VERSION **********

FIGURE 4.1-10. SPN/GEANS FULL LINEARITY RUN (Continued)

Copy available to DDC does not
permit fully legible reproduction

Copy available to DDC does not
permit fully legible reproduction

```
 POS1 =          0.
 POS2 =    -242882.
 POS3 =        -12.
 POS4 =     242830.
   DT =        300.  SECONDS
 BIAS (1G) =     107.059 MICRO G,S
BIAS (0G) =      24.706 MICRO G,S
BIAS COMPENSATION =      82.353 MICRO G,S
ANGLE =     -24.706MICRO RADIANS
 CORR =    1.000000
 SCALE FACTOR =  -809.520(PULSES/SEC/G
  DIS =  90.001404

  MEAN DEVIATION FROM LINEAR =      3.9482 MICRO G,S
  RMS OF DEVIATION FROM MEAN =     15.5222 MICRO G,S
             DEVIATION (RMS) =     16.0165 MICRO G,S

 SUM(X(I)/N)
SQRT ((SUM(X(I)SQ/N) - (MEAN)SQ)
SQRT (SUM (X(I)SQ)/N)

*************** G**2 VERSION ***************
```

FIGURE 4.1-10. SPN/GEANS FULL LINEARITY RUN (Continued)

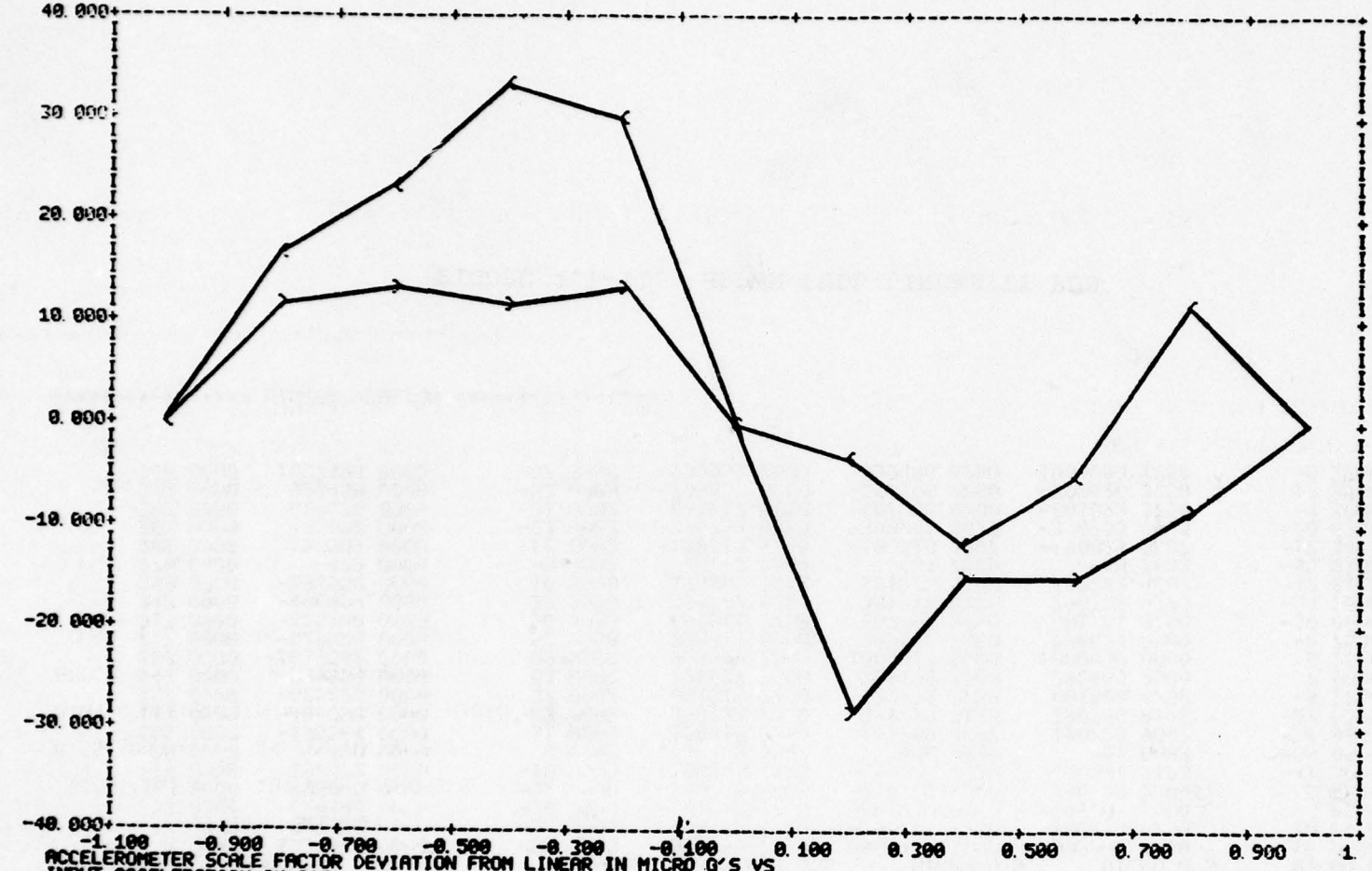


FIGURE 4.1-10. SPN/GEANS FULL LINEARITY RUN (Continued)

Copy available to DDC does not
permit fully legible reproduction

DEVIATION FROM LINEARITY 1 - 1G LINE
COLLINS BRIDGE NO. 261125 INSTALLED 10/15/74 40 SEC COUNTS
20 PT LINEARITY RUN. HARRY'S ROOM

DIV HEAD ANGLE DEGREES	DELTA V.S COUNTS/ 40. SEC	I.A. ANGLE DEGREES	G INPUT MICRO G'S	ACCEL INPUT MICRO G'S	ACCL INPUT-BIAS MICRO G'S	DEV FROM LIN MICRO G'S
0.0000	1037476.0000	-89.9998	-999999.7500	-999467.3750	-999030.8750	18.8750
37.0000	828458.0000	-53.0002	-798637.6250	-798106.8750	-798620.3750	17.2500
53.0004	624146.0000	-35.0002	-601817.8750	-601208.8750	-601322.3750	-4.5000
67.0000	405082.0000	-23.0002	-390734.4375	-390241.5625	-390795.0625	-20.6250
79.0000	197572.0000	-10.0003	-190812.6250	-190316.4687	-190829.9687	-17.3438
90.0000	-472.0000	0.0002	-3.7284	454.7079	-58.7652	-55.0368
101.0000	-198564.0000	11.0002	190812.8750	191289.4687	190779.9687	-36.9063
113.0000	-406098.0000	23.0002	390734.7500	391220.3125	390706.8125	-27.9375
127.0000	-625228.0000	37.0002	601818.2500	602322.3750	601808.8750	-9.3750
143.0000	-829559.0000	53.0002	798637.7500	799138.7500	798645.2500	7.5000
180.0000	-1038562.0000	89.9998	999999.7500	1000513.5000	1000000.0000	0.2500
217.0000	-829523.0000	52.9998	798633.0000	799137.7500	798624.2500	-8.7500
233.0000	-625200.0000	36.9998	601811.8750	602290.3750	601781.8750	-24.0000
247.0000	-406004.0000	22.9993	390727.6875	391216.4375	390702.9375	-24.7500
259.0000	-198550.0001	10.9998	190805.2812	191279.9687	190762.4687	-42.8125
270.0000	-472.0000	-0.0002	-3.7284	454.7079	-58.7652	-55.0368
281.0000	197554.0000	-11.0002	-190812.6250	-190316.4687	-190829.9687	-17.3438
293.0000	405082.0000	-23.0002	-390734.4375	-390241.5625	-390795.0625	-20.6250
307.0000	624176.0000	-37.0002	-601817.8750	-601208.8750	-601322.3750	-4.5000
323.0000	828458.0000	-53.0002	-798637.6250	-798106.8750	-798620.3750	17.2500
360.0000	1037496.0000	-89.9998	-999999.7500	-999486.6250	-1000000.1250	-0.3750

********** LINEAR VERSION **********

FIGURE 4.1-11. HRPWM FULL LINEARITY RUN

Copy available to DDC does not
permit fully legible reproduction

```
 POS1 =       -480.
 POS2 =  -1038562.
 POS3 =       -472.
 POS4 =   1037496.
   DT =         40.  SECONDS
 BIAS (1G) =    513.473 MICRO G,S
BIAS (0G) =    458.561 MICRO G,S
BIAS COMPENSATION =     54.912 MICRO G,S
ANGLE =      3.853MICRO RADIANS
 CORR =   1.000000
 SCALE FACTOR = =25950.722PULSES/SEC/G
  DHC =  89 999771

  MEAN DEVIATION FROM LINEAR =   -13.6918 MICRO G,S
  RMS OF DEVIATION FROM MEAN =    23.6048 MICRO G,S
            DEVIATION (RMS) =    27.2883 MICRO G,S

                                  SUM(X(I)/N)
                                SQRT ((SUM(X(I)SQ/N) - (MEAN)SQ)
                                SQRT (SUM (X(I)SQ)/N)

********** LINEAR VERSION **********
```

FIGURE 4.1-11. HRPWM FULL LINEARITY RUN (Continued)

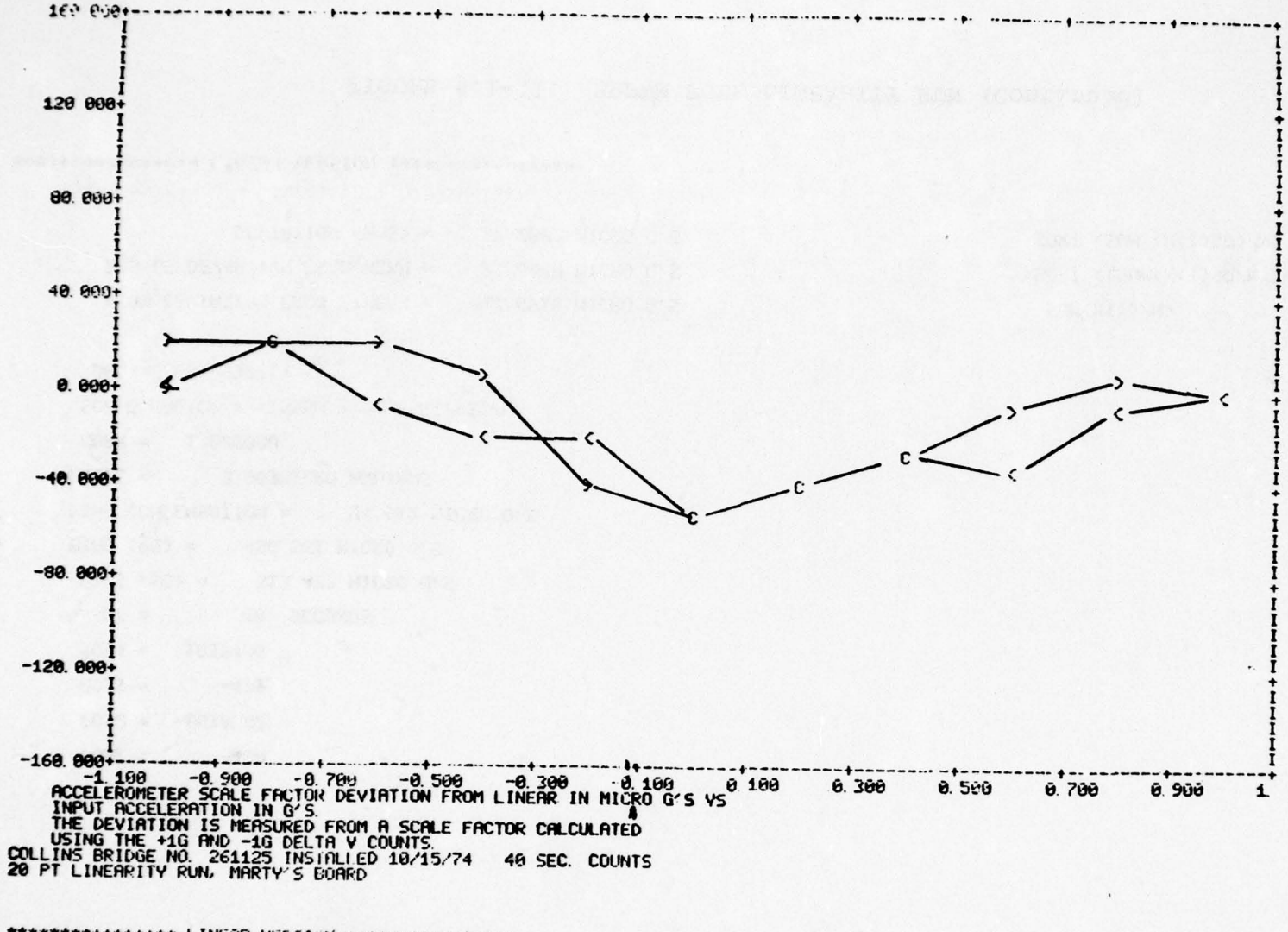


FIGURE 4.1-11. HRPWM FULL LINEARITY RUN (Continued)

DEVIATION FROM LINEARITY + - 1G LINE
COLLINS BRIDA NO. 261[illegible] INSTALLED 10/15/74 40 SEC. COUNTS
20 PT LINEARITY RUN, MARTY'S BOARD

DIV HEAD ANGLE DEGREES	DELTA V/S COUNTS/ 40. SEC	I.A. ANGLE DEGREES	G INPUT MICRO G'S	ACCEL. INPUT MICRO G'S	ACCL. INPUT-BIAS MICRO G'S	DEV FROM LIN MICRO G'S
0.0000	1037476.0000	-89.9998	-999999.7500	-999467.3750	-999980.8750	18.8750
37.0000	828452.0000	-52.9998	-798633.5000	-798181.1250	-798693.6250	29.8750
53.0000	624146.0000	-36.9998	-601812.3750	-601280.0000	-601771.6250	40.7500
67.0000	403049.0000	-22.9998	-390728.0625	-390208.7500	-390688.0125	39.2500
79.0000	197572.0000	-10.9998	-190805.8125	-190331.8125	-190802.8750	2.9375
90.0000	400.0000	0.0002	-3.9947	462.4149	-3.8533	-0.1415
101.0000	-198564.0000	11.0002	190812.8750	191209.4687	190820.4062	7.5313
113.0000	-400093.0000	23.0002	390734.7500	391220.3125	390730.2500	5.5000
127.0000	-625228.0000	37.0002	601818.2500	602322.3750	601830.7500	12.5000
143.0000	-829550.0000	53.0002	798637.7500	799150.7500	798656.2500	18.5000
180.0000	-1038562.0000	89.9998	999999.7500	1000513.5000	1000000.0000	0.2500
217.0000	-829528.0000	52.9998	798633.0000	799137.7500	798635.2500	2.2500
233.0000	-625209.0000	36.9998	601811.8750	602295.3750	601803.7500	-8.1250
247.0000	-406094.0000	22.9998	390727.6875	391216.4375	390736.3750	8.6875
259.0000	-198550.0000	10.9998	190805.2612	191275.9687	190806.9062	1.6250
270.0000	-472.0000	-0.0002	-3.7284	454.7079	-3.8576	-0.1252
281.0000	197554.0000	-11.0002	-190812.6250	-190316.4687	-190785.5312	27.0938
293.0000	405082.0000	-23.0002	-390734.4375	-390241.5625	-390721.6250	12.8125
307.0000	624176.0000	-37.0002	-601817.8750	-601303.8750	-601800.5000	17.3750
323.0000	828458.0000	-53.0002	-798637.6250	-798106.8750	-798609.3750	28.2500
360.0000	1037496.0000	-89.9998	-999999.7500	-999486.6250	-1000000.1250	-0.3750

********** LINEAR VERSION **********

FIGURE 4.11-1. HRPWM FULL LINEARITY RUN (Continued)

```
      =      -480
 POS2 =  -1038562.
 POS3 =      -472.
 POS4 =   1037496.
   DT =        40.  SECONDS
 BIAS (1G) =    513.473 MICRO G,S
BIAS (0G) =    458.561 MICRO G,S
BIAS COMPENSATION =     54.912 MICRO G,S
ANGLE =      3.853MICRO RADIANS
 CORR =   1.000000
 SCALE FACTOR = =25950.722PULSES/SEC/G
  DNC =  89.999771

  MEAN DEVIATION FROM LINEAR =    12.6331 MICRO G,S      SUM(X(I)/N)
  RMS OF DEVIATION FROM MEAN =    13.5226 MICRO G,S      SQRT ((SUM(X(I)SQ/N) - (MEAN)SQ)
            DEVIATION (RMS) =    18.5056 MICRO G,S      SQRT (SUM (X(I)SQ)/N)

********** LINEAR VERSION **********
```

FIGURE 4.1-11. HRPWM FULL LINEARITY RUN (Continued)

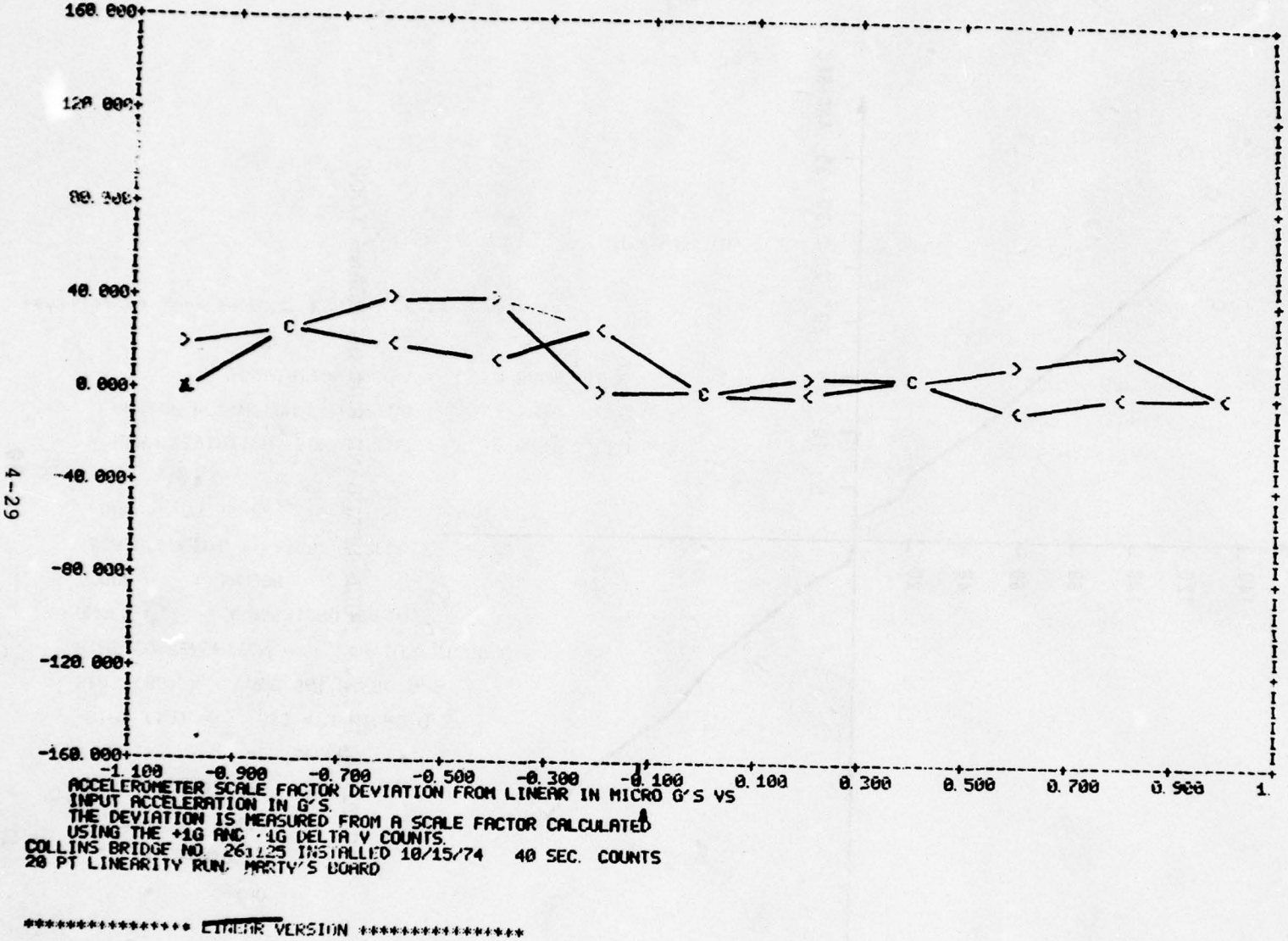


FIGURE 4.1-11. HRPWM FULL LINEARITY RUN (Continued)

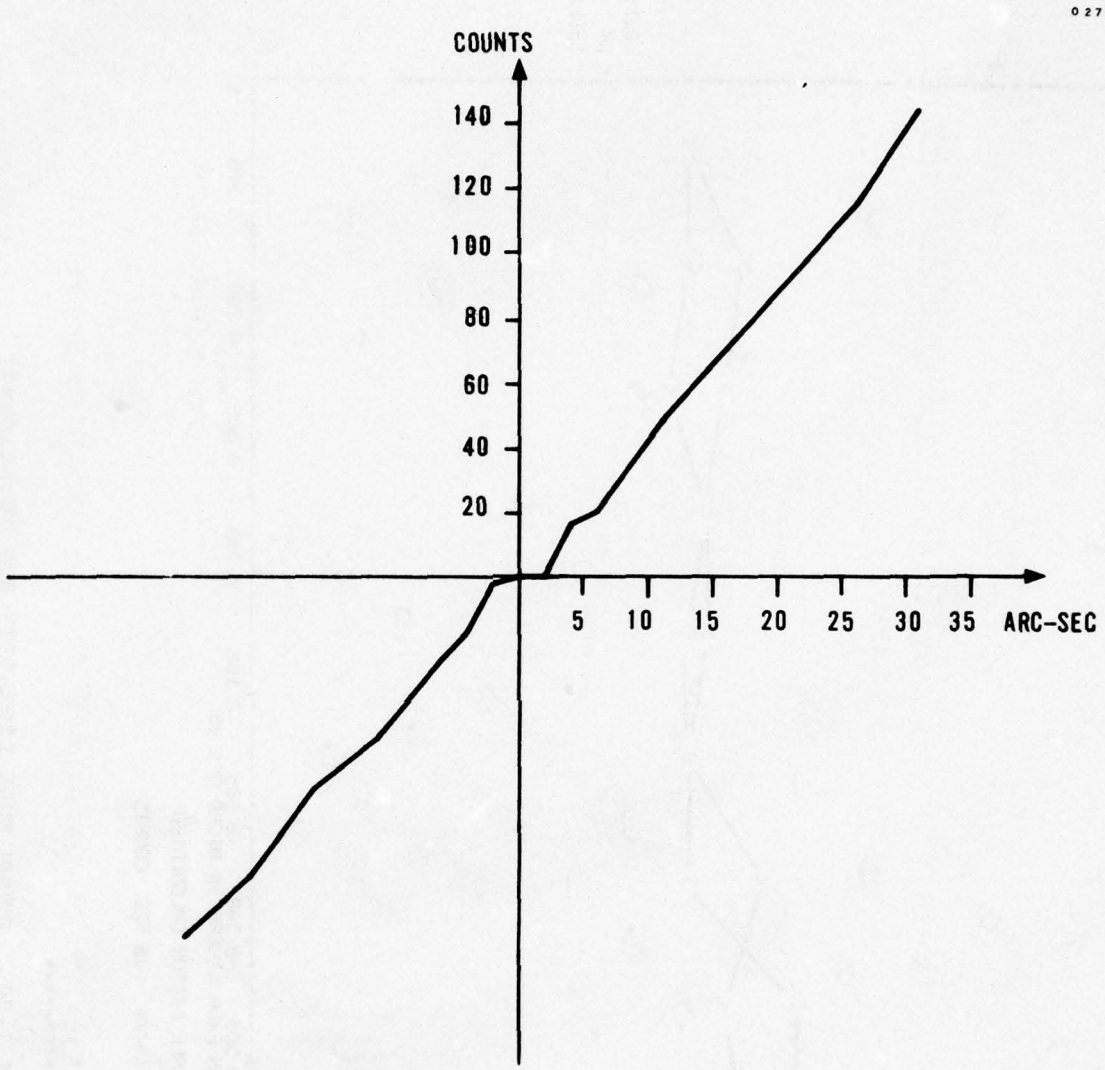


FIGURE 4.1-12. NULL DEADBAND RUN ON GEANS LOOP

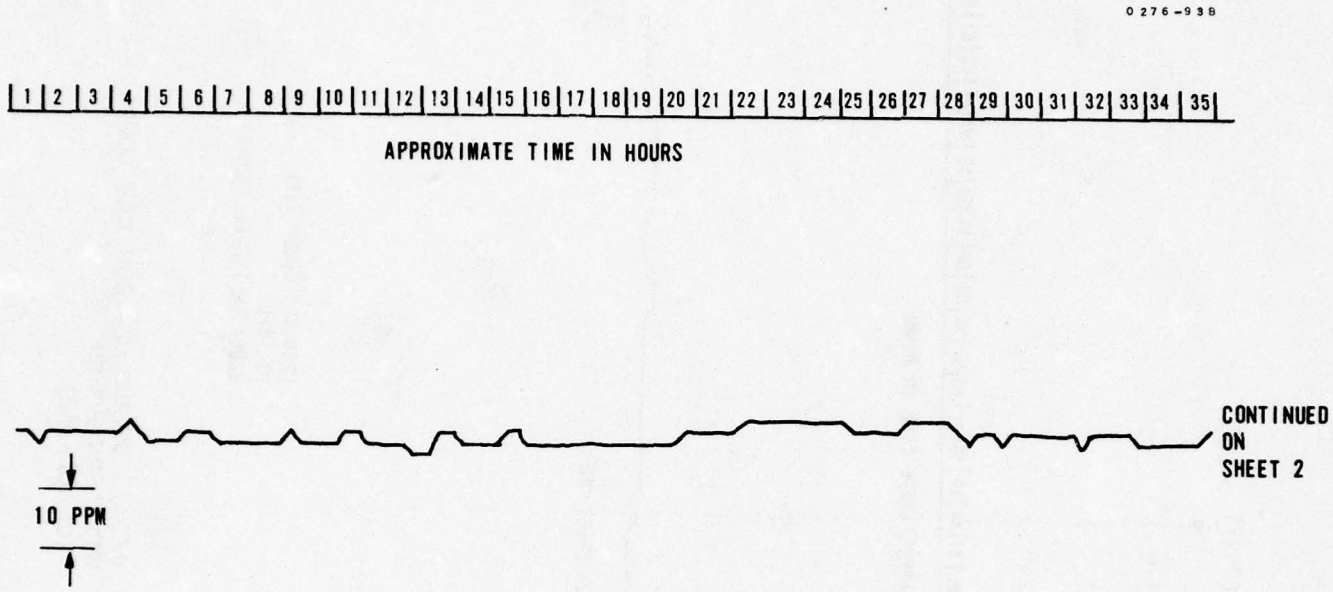


FIGURE 4.1-13. 8/1/75 STABILITY RUN EAR LOOP WITH SPN BOARD

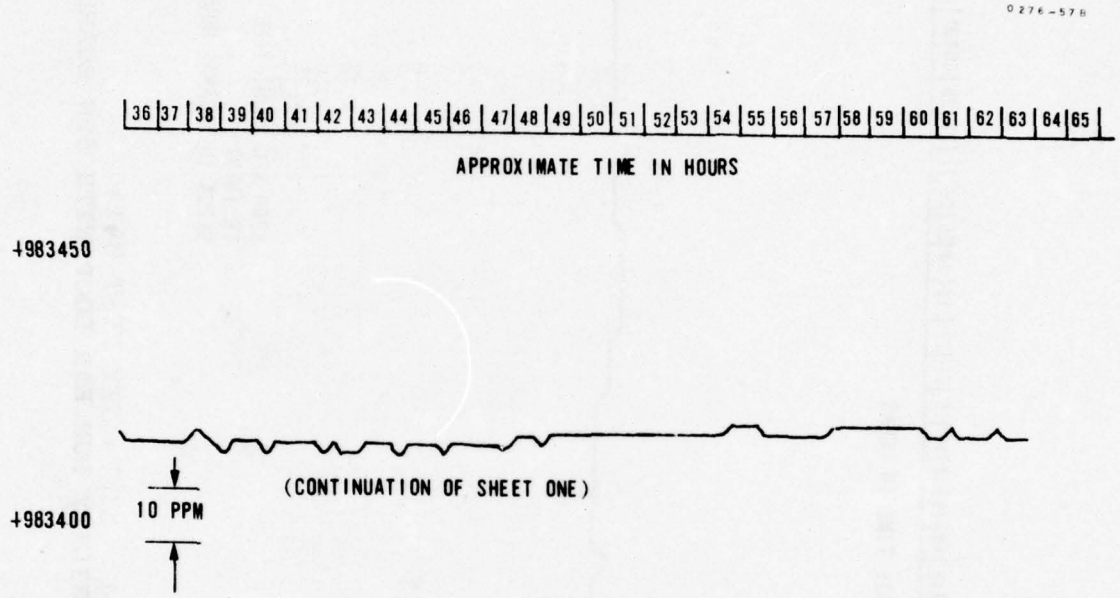


FIGURE 4.1-13. 8/1/75 STABILITY RUN EAR LOOP WITH SPN BOARD (Continued)

DEVIATION FROM LINEARITY + - 1G LINE
DG177 S/N V11 SPN LOOP BASELINE DATA
9/16/75

DIV HEAD ANGLE DEGREES	DELTA V/S COUNTS/1200. SEC	I.A. ANGLE DEGREES	G INPUT MICRO G'S	ACCEL INPUT MICRO G'S	ACCL INPUT-BIAS MICRO G'S	DEV FROM LIN MICRO G'S
90.0000	1742.0000	-0.0684	-1194.1609	-1772.2361	-1242.1931	-48.0322
101.0000	-185840.0000	10.9316	189636.5937	189065.6250	189595.6562	-40.9375
113.0000	-382434.0000	22.9316	389631.5625	389071.9375	389601.9375	-29.6250
127.0000	-590064.0000	36.9316	600860.8750	600305.7500	600835.7500	-25.1250
143.0000	-783772.0000	52.9316	797916.0000	797376.0000	797906.0000	-10.0000
180.0000	-982418.0000	89.9316	999998.8750	999470.0000	1000000.0000	1.1250
217.0006	-785188.0000	53.0684	799353.3750	798816.5000	799346.5000	-6.8750
233.0000	-591948.0000	37.0684	602768.1250	602222.5000	602752.5000	-15.6250
247.0000	-384604.0000	23.0684	391830.0000	391279.6250	391809.6250	-20.3750
259.0000	-188142.0000	11.0684	191981.0625	191407.5937	191937.6250	-43.4375
270.0000	-606.0000	0.0684	1194.1609	616.5184	1146.5615	-47.5994
281.0000	186938.0000	-10.9316	-189636.5937	-190182.7187	-189652.6875	-16.0938
293.0000	383518.0000	-22.9316	-389631.5625	-390174.7500	-389644.7500	-13.1875
307.0000	591136.0000	-36.9316	-600860.8750	-601396.5000	-600866.5000	-5.6250
323.0000	784826.0000	-52.9316	-797916.0000	-798448.3750	-797918.3750	-2.3750
360.0000	983460.0000	-89.9316	-999998.8750	-1000530.0000	-1000000.0000	-1.1250
37.0000	786240.0000	-53.0684	-799353.3750	-799886.8750	-799356.8750	-3.5000
53.0000	593010.0000	-37.0684	-602768.1250	-603303.0000	-602773.0000	-4.8750
67.0000	385678.0000	-23.0684	-391830.0000	-392372.2500	-391842.2500	-12.2500
79.0000	189250.0000	-11.0684	-191981.0625	-192534.8437	-192004.8125	-23.7500
90.0000	1730.0000	-0.0684	-1194.1609	-1760.0278	-1229.9849	-35.8240

********** LINEAR VERSION **********

FIGURE 4.1-14. LINEARITY TEST DATA

```
 POS1 =      1742.
 POS2 =   -982418.
 POS3 =      -606.
 POS4 =    983460
   DT =      1200. SECONDS
 BIAS (1G) =   -530.043 MICRO G,S
BIAS (0G) =   -577.859 MICRO G,S
BIAS COMPENSATION =     47.816 MICRO G,S
ANGLE =  -1194.377MICRO RADIANS
 CORR =   1.000000
 SCALE FACTOR =  -019.1158PULSES/SEC/G
  DHC =  90.060420

  MEAN DEVIATION FROM LINEAR =   -19.2910 MICRO G,S
  RMS OF DEV+ATION FROM MEAN =    15.6481 MICRO G,S
            DEVIATION (RMS) =    24.8396 MICRO G,S

                                  SUM(X(I)/N)
                                SQRT ((SUM(X(I)SQ/N) - (MEAN)SQ)
                                SQRT (SUM (X(I)SQ)/N)

*************** LINEAR VERSION ***************
```

FIGURE 4.1-14. LINEARITY TEST DATA (Continued)

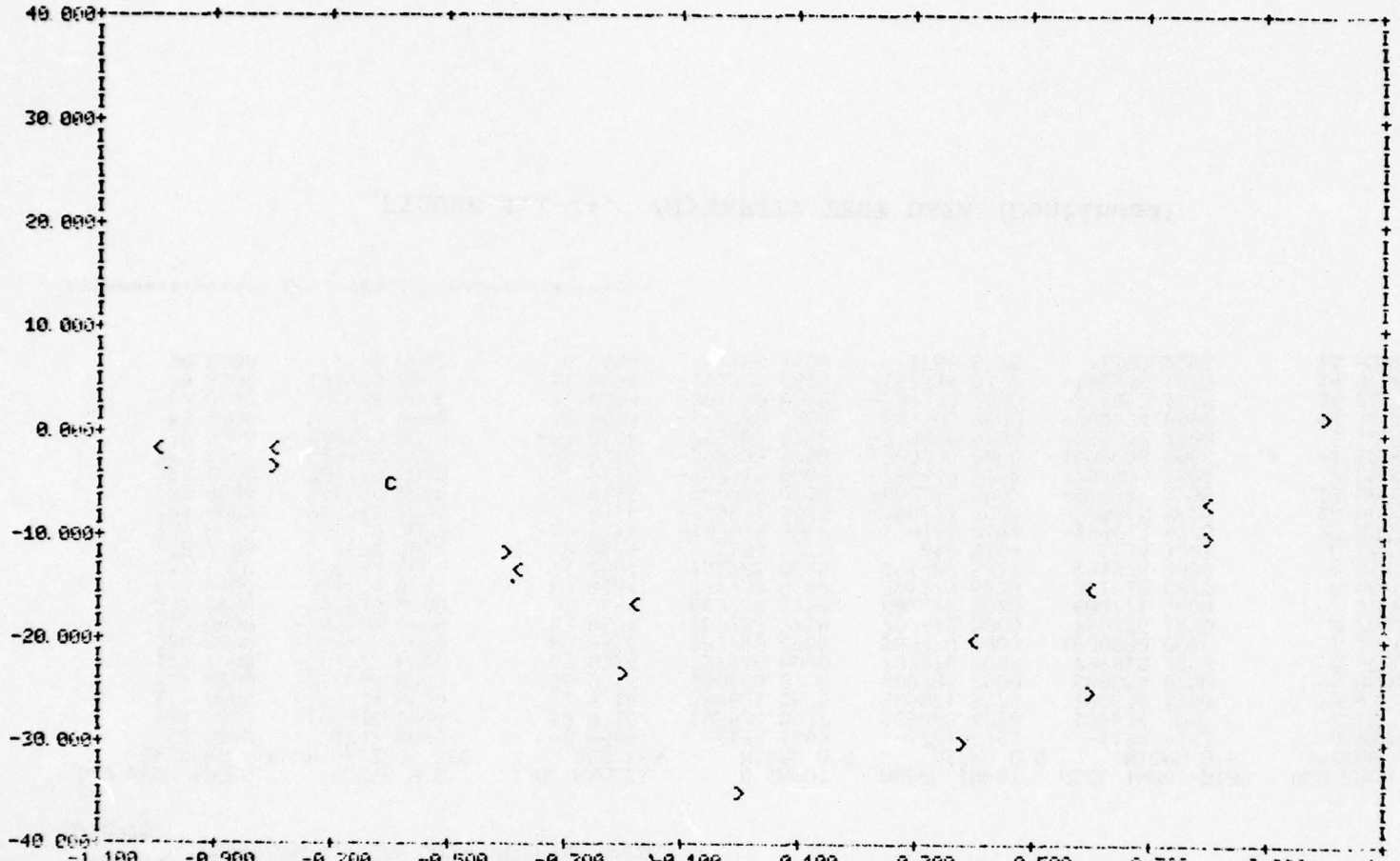


FIGURE 4.1-14. LINEARITY TEST DATA (Continued)

DEVIATION FROM LINEARITY + - 1G LINE
DG177 S/N V11 SPN LOOP BASELINE DATA
9/16/75

DIV HEAD ANGLE DEGREES	DELTA V,S COUNTS/1200. SEC	I.A. ANGLE DEGREES	G INPUT MICRO G'S	ACCEL INPUT MICRO G'S	ACCL INPUT-BIAS MICRO G'S	DEV FROM LIN MICRO G'S
90.0000	1742.0000	-0.0684	-1194.1609	-1772.2361	-1194.4343	-0.2734
101.0000	-185840.0003	10.9316	189636.5937	189065.6250	189634.4062	-2.1875
113.0000	-382434.0000	22.9316	389631.5625	389071.9375	389631.1250	-0.4375
127.0000	-590064.0000	36.9316	600860.8750	600305.7500	600854.8750	-6.0000
143.0000	-783772.0000	52.9316	797916.0000	797376.0000	797915.6250	-0.3750
180.0000	-982418.0000	89.9316	999998.8750	999470.0000	1000000.0000	1.1250
217.0000	-785188.0000	53.0684	799353.3750	798816.5000	799356.1250	2.7500
233.0000	-591948.0000	37.0684	602768.1250	602222.5000	602771.5000	3.3750
247.0000	-384604.0000	23.0684	391830.0000	391279.6250	391838.6875	8.6875
259.0000	-188142.0000	11.0684	191981.0625	191407.5937	191976.2500	-4.8125
270.0000	-606.0000	0.0684	1194.1609	616.5184	1194.3203	0.1594
281.0000	186938.0000	-10.9316	-189636.5937	-190182.7187	-189613.9375	22.6563
293.0000	383518.0000	-22.9316	-389631.5625	-390174.7500	-389615.5625	16.0000
307.0000	591136.0000	-36.9316	-600860.8750	-601396.5000	-600847.3750	13.5000
323.0000	784826.0000	-52.9316	-797916.0000	-798448.3750	-797908.7500	7.2500
360.0000	983460.0000	-89.9316	-999998.8750	-1000530.0000	-1000000.0000	-1.1250
37.0000	786240.0000	-53.0684	-799353.3750	-799886.8750	-799347.2500	6.1250
53.0000	593010.0000	-37.0684	-602768.1250	-603303.0000	-602754.0000	14.1250
67.0000	385678.0000	-23.0684	-391830.0000	-392372.2500	-391813.1875	16.8125
79.0000	189250.0000	-11.0684	-191981.0625	-192534.8437	-191966.1875	14.8750
90.0000	1730.0000	-0.0684	-1194.1609	-1760.0278	-1182.2261	11.9348

********** G**2 VERSION **********

FIGURE 4.1-14. LINEARITY TEST DATA (Continued)

```
 POS1 =      1742.
 POS2 =   -982418.
 POS3 =      -606.
 POS4 =    983460.
   DT =      1200.  SECONDS
 BIAS (1G) =   -530.043 MICRO G,S
BIAS (0G) =   -577.859 MICRO G,S
RIAS COMPENSATION =     47.816 MICRO G,S
ANGLE =  -1194.377MICRO RADIANS
 CORR =   1.000000
 SCALE FACTOR =  -819.1158PULSES/SEC/G
  DHC =  90.068420

  MEAN DEVIATION FROM LINEAR =     5.9126 MICRO G,S      SUM(X(I)/N)
  RMS OF DEV+ATION FROM MEAN =     7.9124 MICRO G,S      SQRT ((SUM(X(I)SQ/N) - (MEAN)SQ)
             DEVIATION (RMS) =     9.8775 MICRO G,S      SQRT (SUM (X(I)SQ)/N)

*************** G**2 VERSION ***************
```

FIGURE 4.1-14. LINEARITY TEST DATA (Continued)

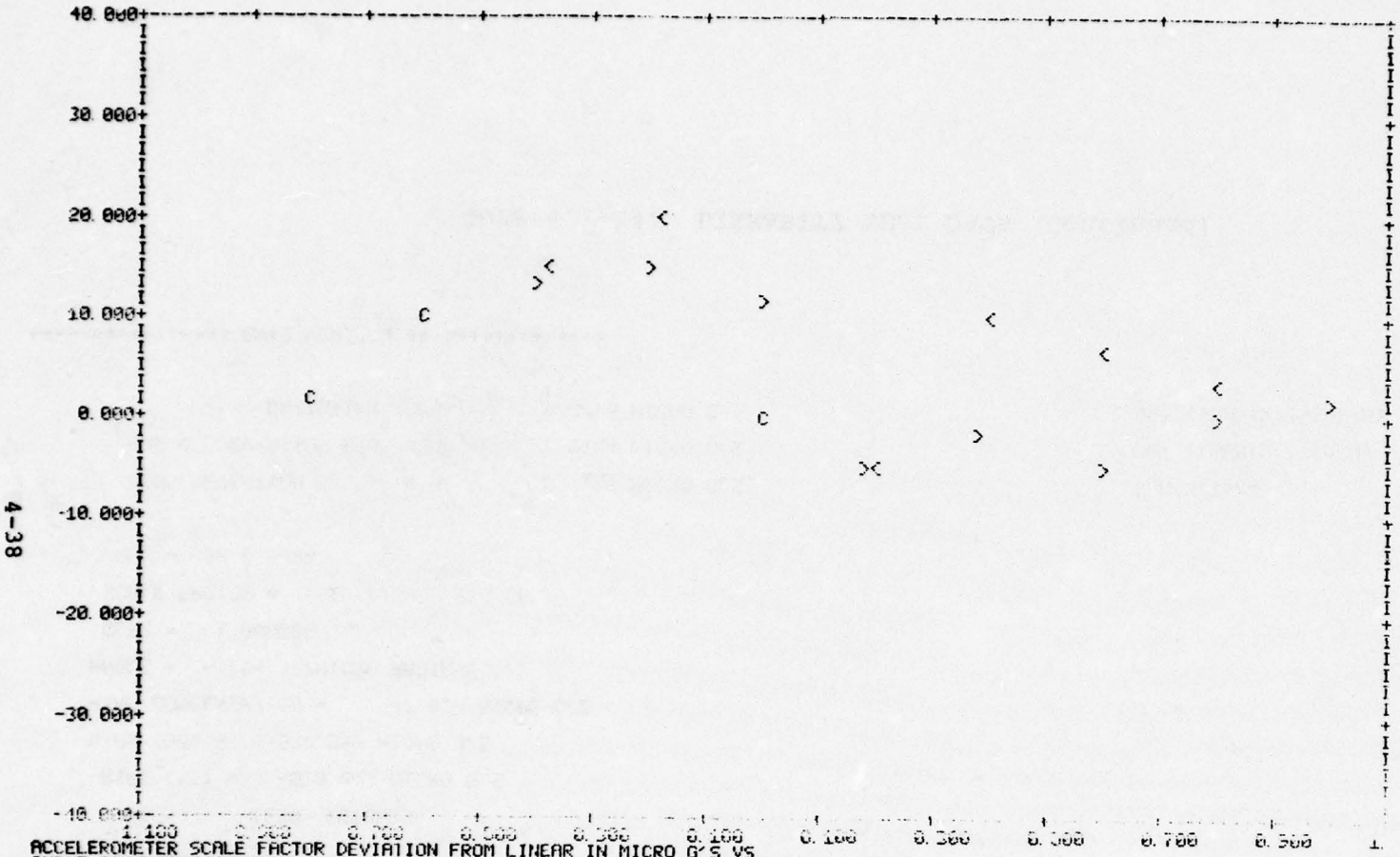


FIGURE 4.1-14. LINEARITY TEST DATA (Continued)

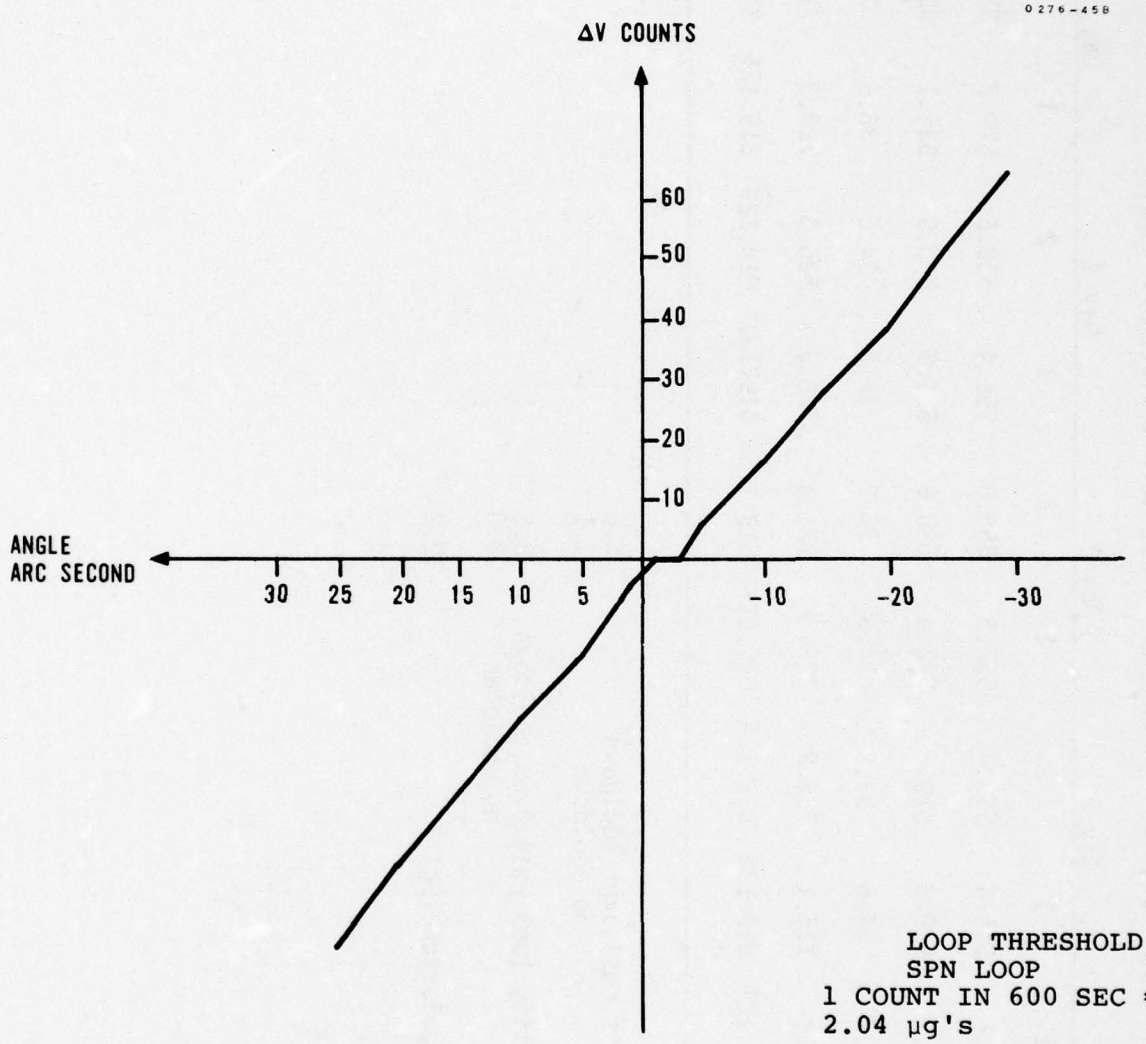


FIGURE 4.1-15. 9/22/75 NULL DEADBAND TEST
SPN BASELINE DATA - 600 SEC COUNT TIME

TABLE 4.1-1. SPN/GEANS FIVE-DAY STABILITY TEST

	Day 1		Day 2		Day 3		Day 4		Day 5	
	1	2	1	2	1	2	1	2	1	2
[illegible] Bias	553.4	554.4	554.4	553.4	557.5	559.0	556.4	558.5	570.7	570.7
1g Bias	516.8	515.7	519.8	519.8	522.9	520.8	523.9	523.9	534.1	534.1
Δ Bias	36.6	38.7	34.6	33.6	34.6	38.2	32.5	34.6	36.6	36.6
Al Angle	716.2	713.1	715.1	716.2	722.3	721.8	725.3	725.3	723.3	727.4
S.F.	819.125	819.124	819.134	819.134	819.127	819.125	819.131	819.129	819.126	819.124

1 g Bias Stability (μg's rms)	over cooldown	5.6
	no cooldown	1.1
1 g Scale Factor Stability (ppm rms)	Over cooldown	8.5
	no cooldown	2.0
Linearity: Standard Deviation (μg)		-19.2
Threshold (arc-second)		2

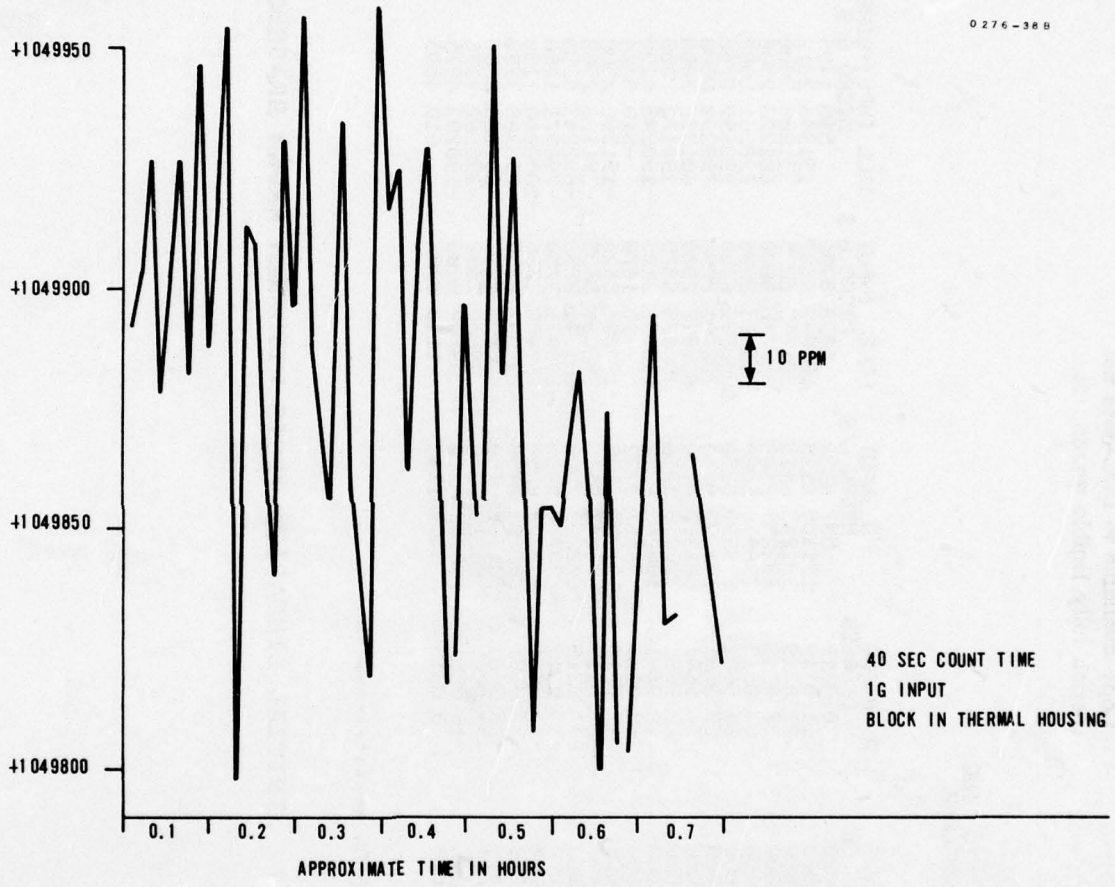


FIGURE 4.1-16. STABILITY RUN EAR LOOP WITH HRPWM BOARD

Copy available to DDC does not
permit fully legible reproduction

DEVIATION FROM LINEARITY + - 1G LINE
DG177 S/N V11 HRPWM LOOP
8/20/75

DIV HEAD ANGLE DEGREES	DELTA V,S COUNTS/ 40. SEC	I.A. ANGLE DEGREES	G INPUT MICRO G'S	ACCEL INPUT MICRO G'S	ACCL INPUT-BIAS MICRO G'S	DEV FROM LIN MICRO G'S
270.0000	1150.0000	0.0319	557.1332	1096.8301	595.1495	38.0164
281.0000	201148.0000	11.0319	191355.8125	191847.9687	191346.2812	-9.5313
293.0000	410694.0000	23.0319	391243.8125	391705.6875	391204.0000	-39.8125
307.0000	631948.0000	37.0319	602259.7500	602730.0000	602228.2500	-31.5000
323.0000	838218.0000	53.0319	798970.5000	799463.2500	798961.5000	-9.0000
360.0000	1049002.0000	89.9681	999999.6250	1000501.6250	999999.8750	0.2500
37.0000	837514.0000	52.9681	798299.8750	798791.7500	798290.0000	-9.8750
53.0000	631012.0000	36.9681	601369.8750	601837.2500	601335.5000	-34.3750
67.0000	409612.0000	22.9681	390218.1250	390673.6875	390172.0000	-46.1250
79.0000	199994.0000	10.9681	190262.0312	190747.3125	190245.6250	-16.4063
90.0000	-18.0000	-0.0319	-557.1332	-17.1678	-518.8484	38.2848
101.0000	-200054.0000	-11.0319	-191355.8125	-190804.5625	-191306.2500	49.5625
113.0000	-409636.0000	-23.0319	-391243.8125	-390696.5625	-391198.2500	45.5625
127.0000	-630912.0000	-37.0319	-602259.7500	-601741.8750	-602243.6250	16.1250
143.0000	-837178.0000	-53.0319	-798970.5000	-798471.3750	-798973.1250	-2.6250
180.0000	-1047950.0000	-89.9681	-999999.6250	-999498.3750	-1000000.1250	-0.5000
217.0000	-836478.0000	-52.9681	-798299.8750	-797803.6250	-798305.3750	-5.5000
233.0000	-629978.0000	-36.9681	-601369.8750	-600851.1250	-601352.8750	17.0000
247.0000	-408550.0000	-22.9681	-390218.1250	-389660.7500	-390162.4375	55.6875
264.0000	-198898.0000	-10.9681	-190262.0312	-189702.0000	-190203.6875	58.3438
270.0000	1166.0000	0.0319	557.1332	1112.0901	610.4095	53.2764

********** LINEAR VERSION **********

FIGURE 4.1-17. INITIAL LINEARITY TESTS WITH NEW HRPWM BRASSBOARD

Copy available to DDC does not
permit fully legible reproduction

```
 POS1 =      1150.
 POS2 =   1049002.
 POS3 =       -18.
 POS4 =  -1047950.
   DT =        40.  SECONDS
 BIAS (1G) =    501.681 MICRO G,S
BIAS (0G) =    539.831 MICRO G,S
BIAS COMPENSATION =    -38.151 MICRO G,S
ANGLE =    556.999MICRO RADIANS
 CORR =   1.000000
 SCALE FACTOR = 26211.8984PULSES/SEC/G
  DHC = 269.968079

  MEAN DEVIATION FROM LINEAR =     7.9457 MICRO G,S      SUM(X(I)/N)
  RMS OF DEV+ATION FROM MEAN =    32.7126 MICRO G,S      SQRT ((SUM(X(I)SQ/N) - (MEAN)SQ)
            DEVIATION (RMS) =    33.6638 MICRO G,S      SQRT (SUM (X(I)SQ)/N)

********** LINEAR VERSION **********
```

FIGURE 4.1-17. INITIAL LINEARITY TESTS WITH NEW HRPWM BRASSBOARD (Continued)

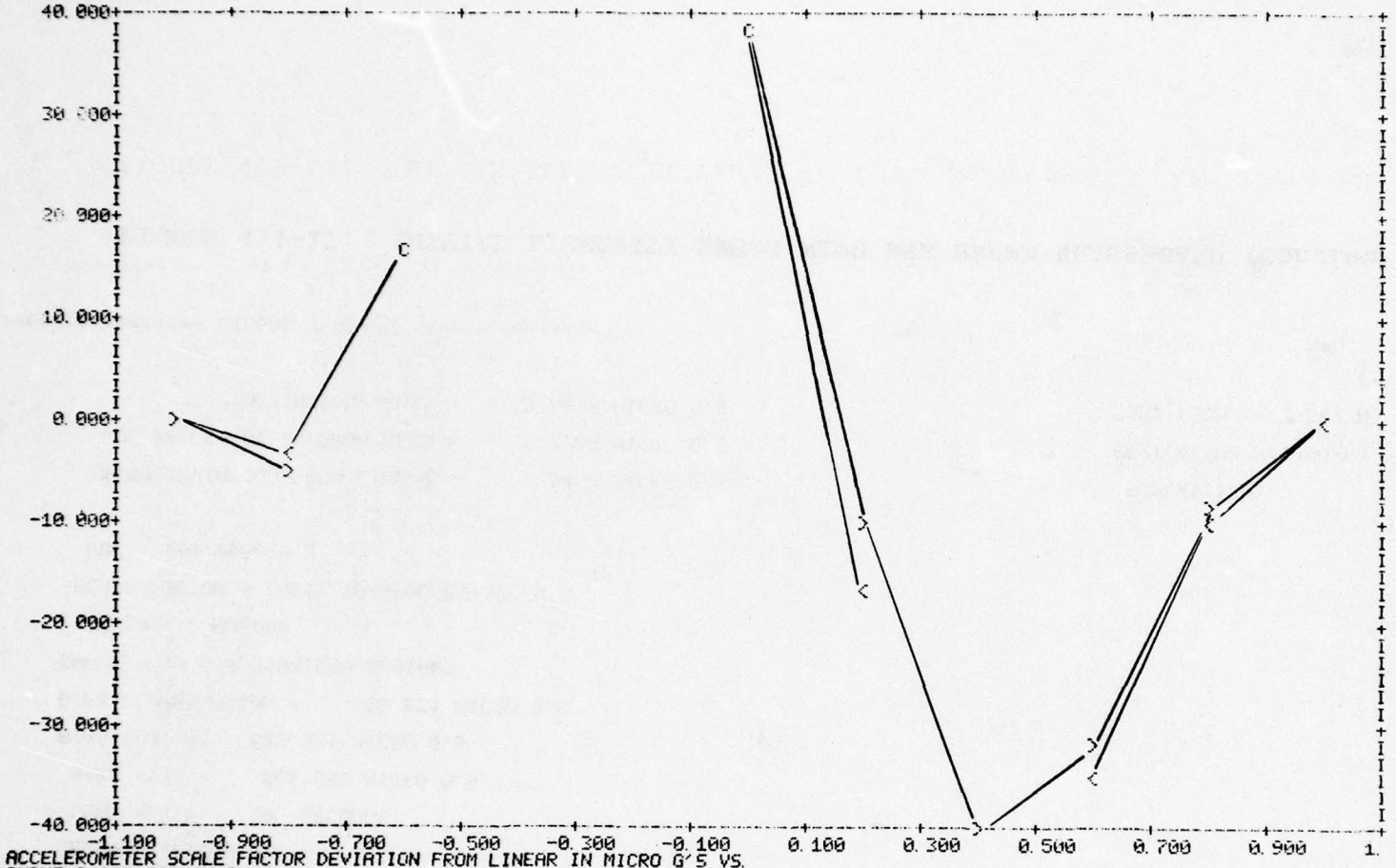


FIGURE 4.1-17. INITIAL LINEARITY TESTS WITH NEW HRPWM BRASSBOARD (Continued)

DEVIATION FROM LINEARITY + - 1G LINE
DG177 S/N V11 HRPWM LOOP
8/20/75

DIV HEAD ANGLE DEGREES	DELTA V,S COUNTS/ 40. SEC	I.A. ANGLE DEGREES	G INPUT MICRO G'S	ACCEL INPUT MICRO G'S	ACCL INPUT-BIAS MICRO G'S	DEV FROM LIN MICRO G'S
270.0000	1150.0000	0.0319	557.1332	1096.8301	557.0203	-0.1129
281.0000	201148.0000	11.0319	191355.8125	191847.9687	191315.4375	-40.3750
293.0000	410694.0000	23.0319	391243.8125	391705.6875	391180.7500	-63.0625
307.0000	631948.0000	37.0319	602259.7500	602730.0000	602213.1250	-46.6250
323.0000	838218.0000	53.0319	798970.5000	799463.2500	798953.8750	-16.6250
360.0000	1049002.0000	89.9681	999999.6250	1000501.6250	999999.8750	0.2500
37.0000	837514.0000	52.9681	798299.8750	798791.7500	798282.2500	-17.6250
53.0000	631012.0000	36.9681	601369.8750	601837.2500	601320.2500	-49.6250
67.0000	409612.0000	22.9681	390218.1250	390673.6875	390148.6875	-69.4375
79.0000	199994.0000	10.9681	190262.0312	190747.3125	190214.7187	-47.3125
90.0000	-18.0000	-0.0319	-557.1332	-17.1678	-556.9777	0.1555
101.0000	-200054.0000	-11.0319	-191355.8125	-190804.5625	-191337.0937	18.7188
113.0000	-409636.0000	-23.0319	-391243.8125	-390696.5625	-391221.5000	22.3125
127.0000	-630912.0000	-37.0319	-602259.7500	-601741.8750	-602258.7500	1.0000
143.0000	-837178.0000	-53.0319	-798970.5000	-798471.3750	-798980.7500	-10.2500
180.0000	-1047950.0000	-89.9681	-999999.6250	-999498.3750	-1000000.1250	-0.5000
217.0000	-836478.0000	-52.9681	-798299.8750	-797803.6250	-798313.1250	-13.2500
233.0000	-629978.0000	-36.9681	-601369.8750	-600851.1250	-601368.1250	1.7500
247.0000	-408550.0000	-22.9681	-390218.1250	-389660.7500	-390185.7500	32.3750
259.0000	-198898.0000	-10.9681	-190262.0312	-189702.0000	-190234.5937	27.4375
270.0000	1166.0000	0.0319	557.1332	1112.0901	572.2803	15.1471

********** G**2 VERSION **********

FIGURE 4.1-17. INITIAL LINEARITY TESTS WITH NEW HRPWM BRASSBOARD (Continued)

```
 POS1 =      1150
 POS2 =   1049002.
 POS3 =       -18.
 POS4 =  -1047950.
   DT =        40.  SECONDS
 BIAS (1G) =    501.681 MICRO G,S
BIAS (0G) =    539.831 MICRO G,S
BIAS COMPENSATION =    -38.151 MICRO G,S
ANGLE =    556.999MICRO RADIANS
 CORR =   1.000000
 SCALE FACTOR = 26211.8984PULSES/SEC/G
  DHC = 269 968079

  MEAN DEVIATION.FROM LINEAR =   -12.1740 MICRO G,S
  RMS OF DEV+ATION FROM MEAN =    29.2298 MICRO G,S
            DEVIATION (RMS) =    31.6636 MICRO G,S

 SUM(X(I)/N)
SQRT ((SUM(X(I)SQ/N) - (MEAN)SQ)
SQRT (SUM (X(I)SQ)/N)

********** G**2 VERSION **********
```

FIGURE 4.1-17. INITIAL LINEARITY TESTS WITH NEW HRPWM BRASSBOARD (Continued)

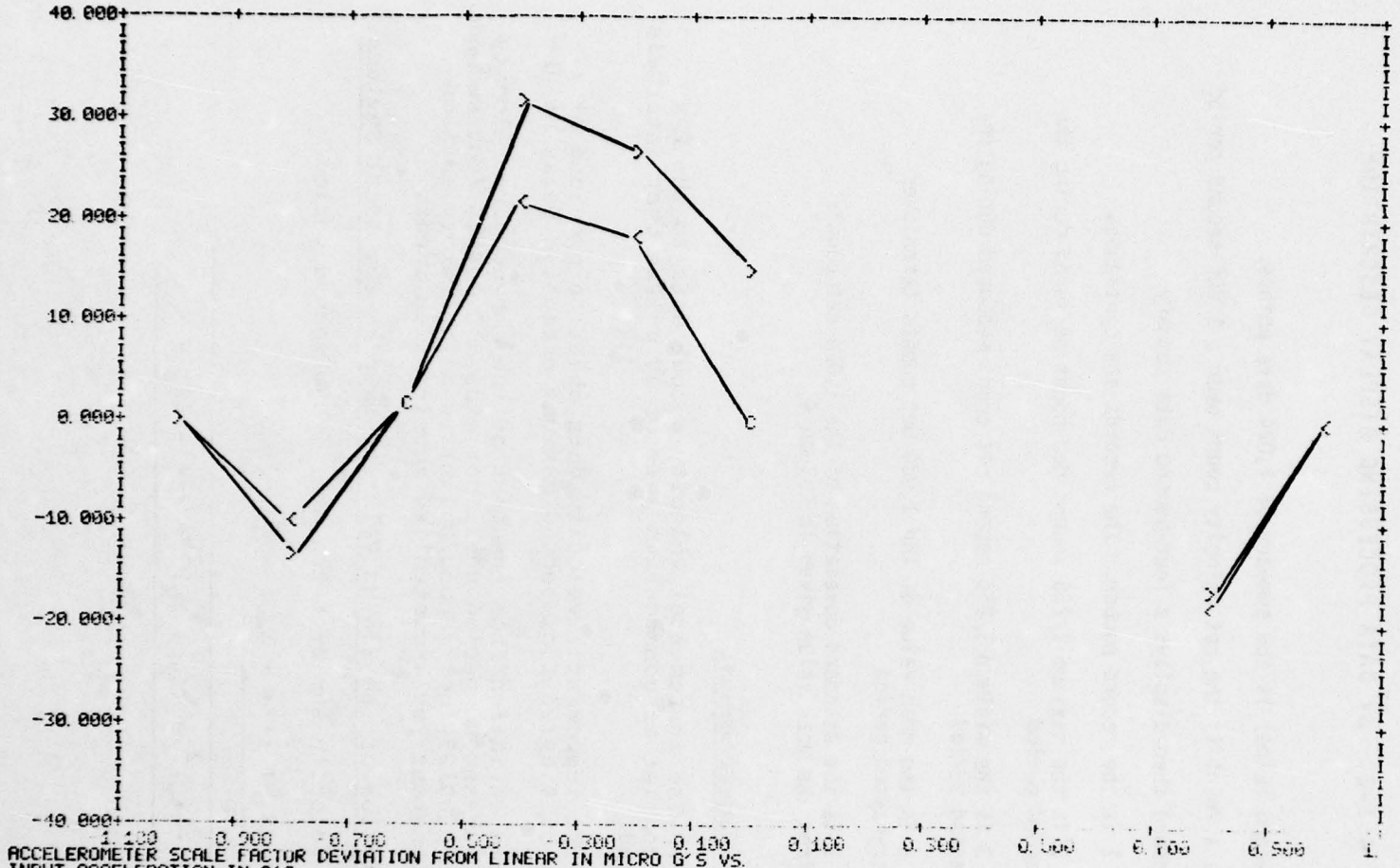


FIGURE 4.1-17. INITIAL LINEARITY TESTS WITH NEW HRPWM BRASSBOARD

TABLE 4.1-2. ΔV DATA PROCESSING DISPLAY DESCRIPTION

Each Record (Line) is the summary of 1,024 data points.

Each Data Point is the net velocity count over a 1/256 second period

Each record then displays a four-second data summary

Column 1 is the record number. The records are contiguous

Column 2 is the maximum 1/256 second net count measured during the four-second period

Column 3 is the minimum 1/256 second net count measured during the four-second period

Column 4 is the mean value of the 1,024 net counts taken over the four-second period

Column 5 is the standard deveiation of the 1,024 net counts taken from the mean value given in Column 4

Velocity Loop Requirements:

Sample Period: The incremental velocity output data to the EAR System shall consist of consecutive sums of ΔV pulses over intervals of 1/256 second.

Resolution: The incremental velocity data shall be provided at a ΔV resolution of 0.00125 foot/second maximum effective pulse weight.

Noise: The rms deviation from the mean of the consecutive velocity sums over a four-second period shall not exceed 0.000875 foot/second (0.7 pulse at 0.00125 foot/second/pulse) in a laboratory environment with a constant, well-controlled acceleration input.

Standard Deviation of the 256 Hz Velocity Samples for Ideal Systems:

X_m = The net velocity sum over the mth, 1/256 second period

$$X_M = \frac{X_1 + X_2 + X_3 + \cdots + X_m}{m}$$

$$\text{Std Dev} = \sqrt{\frac{(X_1 - X_M)^2 + (X_2 - X_M)^2 + \cdots + (X_m - X_M)^2}{m}}$$

101 DEGREES

RECD	MAX	MIN	MEAN	DEV
1	-9	-28	-19.30273	1.78484
2	-9	-26	-19.29297	1.70996
3	-9	-24	-19.29785	1.70653
4	-9	-24	-19.29395	1.73838
5	-10	-24	-19.31055	1.71313
6	-8	-24	-19.29492	1.81759
7	-9	-26	-19.29102	1.72676
8	-9	-24	-19.31934	1.60461
9	-9	-24	-19.29395	1.66961
10	-10	-24	-19.29785	1.69331

113 DEGREES

RECD	MAX	MIN	MEAN	DEV
1	-36	-52	-39.86523	1.30110
2	-36	-44	-39.84570	1.22053
3	-35	-42	-39.84082	1.16634
4	-36	-44	-39.84375	1.18709
5	-36	-53	-39.88672	1.43979
6	-19	-53	-39.85742	1.47745
7	-36	-52	-39.86719	1.28468
8	-36	-53	-39.88965	1.38860
9	-35	-44	-39.83887	1.22255
10	-34	-44	-39.84082	1.20099

127 DEGREES

RECD	MAX	MIN	MEAN	DEV
1	-58	-64	-61.47266	1.26282
2	-58	-64	-61.47852	1.22135
3	-59	-64	-61.48047	1.21091
4	-58	-64	-61.47070	1.22833
5	-58	-64	-61.47559	1.25837
6	-58	-64	-61.47754	1.17904
7	-58	-64	-61.47754	1.23566
8	-58	-64	-61.46973	1.22035
9	-30	-64	-61.45020	1.58345
10	-58	-64	-61.47168	1.27207

FIGURE 4.1-18. DATA SAMPLES AT 256 Hz

Case I. Assume a mean net count of 1.0 pulse and oscillation about the mean every sample cycle.

0. 2, 0, 2, 0, 2, ·····, 0, 2

$$\text{Std Dev} = \frac{(2-1)^2 + (0-1)^2 + \cdots}{m} = \frac{m(1)^2}{m} = 1.0$$

Case II. Assume a mean net count of 2.0 pulses and a net count of 2.0 pulses each sample cycle. 2, 2, 2, ····· 2

$$\text{Std Dev} = \frac{(2-2)^2 + (2-2)^2 + \cdots}{m} = 0$$

T_c = 1,048,576 Hz Pulse Weight = 0.000306 foot/second/pulse

$$\frac{2 \text{ Pulses}}{(1/256)\text{sec}} = \frac{2}{4{,}096} \times 10 \text{ g's} = 0.0004883 \text{ g's}$$

204 Std Dev nulls between 1 g and 0 g in one quad.

Given:

ΔV Clock Frequency: 1,048,576 Hz

Dither Frequency: 2,048 Hz

Data Sample Rate: 256 Hz

There are:

512 Pulses per Dither Cycle

8 Dither Cycles per Data Cycle

4,096 Pulses per Data Cycle

Observations:

1 g Net Count = 409.6 counts per data sample cycle

1 g Net Count (Information Reproduction Cycle) not synchronous with the Data Sample Cycle.

Perfect Noise Free Measurement System:

1 g: Net counts per Data Sample Cycle: Info Repro Cycle [410, 410, 408, 410, 410]

5 Sample Cycle Average = 409.2 counts

5 Sample Cycle Std Deviation = 0.8 pulses at 1,048,546 Hz

1 g: Net count per Dither Cycle = 51.2

	Sum
52, 52, 50, 52, 52, 50, 52, 50	410
52, 52, 50, 52, 52, 50, 52, 50	410
52, 50, 52, 50, 52, 50, 52, 50	408
52, 52, 50, 52, 52, 50, 52, 50	410
52, 52, 50, 52, 52, 50, 52, 50	410
5 Cycle Average	409.2

1 g Data Noise Frequency

1 net pulses every 5 Data Sample Cycles

$$\frac{256 \text{ Hz}}{5} = 51.2 \text{ Hz}$$

The desired puse weight of 0.0004883 g's can be obtained by operating the loop ΔV clocking at 1,048,576 Hz, yielding a pulse weight of 0.000306 foot/second/pulse. The first step in this new effort was to change the clocking rate of the loop from 8,192 to 1,048,576 Hz. It was seen that the loop still operated, but the data was still quite noisy. A step by step process of elimination was then followed using computer typeouts of data to isolate the noise sources. Data was taken by shorting the input to the comparator, then the amplifier, then the demodulator. By using this method, it was seen that most of the noise was being generated by the multiplier being used as a demodulator.

A new demodulator circuit which was already being considered for use in SPN/GEANS was put into the brassboard, as well as two decoupling capacitors on the comparator and the amplifier. The amplifier gain was then adjusted to restore loop gain to it's proper value.

In order to look at the noise and loop behavior in more depth, it was decided to sample the data at a 2,048 Hz rate. Figures 4.1-19 and 4.1-20 show the reduced data from this test. Each count is one dither cycle. Theoretically, assuming perfect operation, the count should not change more than two counts from one cycle to the next. If it does, either the gain is not set properly or there is loop noise. It can be seen from the data that occasionally a four-count jump is seen. Evaluating the impact of this can best be done by looking at the standard deviation. The results of this part of the investigation indicated that good results could be expected from this configuration, and it was decided to proceed with full testing.

11/21/75

09 $T_c = 1,048,576$ Hz DATA SAMPLE RATE = 2048 Hz

$R_f = 4.12K$

NET COUNT EACH DITHER CYCLE								SUM OF COLUMN 1→8	RUNNING MEAN OF COLUMN 9	RUNNING STD DEVIATION OF COLUMN 9
0	1024	4	-4)					9	10	11
0	0	0	0	0	0	0	2	2.00000	2.00000	0.00000
0	0	0	0	0	0	0	0	0.00000	1.00000	1.00000
0	0	0	-2	0	0	0	2	0.00000	0.66667	0.94281
0	0	0	0	0	-2	0	0	-2.00000	0.00000	1.41421
0	0	0	0	0	0	0	0	0.00000	0.00000	1.26491
0	0	-2	0	0	0	0	0	-2.00000	-0.33333	1.37437
2	0	0	0	0	0	0	0	2.00000	0.00000	1.51186
0	0	0	0	0	0	0	0	0.00000	0.00000	1.41421
-2	0	0	0	-2	0	0	0	-4.00000	-0.44444	1.83249
0	0	0	0	0	2	0	0	2.00000	-0.20000	1.88680
0	0	0	0	0	0	0	0	0.00000	-0.18182	1.79991
0	0	2	0	0	0	0	0	2.00000	0.00000	1.82574
0	0	0	0	0	0	0	0	0.00000	0.00000	1.75412
0	0	-2	0	-2	0	0	0	-4.00000	-0.28571	1.97949
0	0	0	0	0	0	0	0	0.00000	-0.26667	1.91369
0	0	0	0	0	-2	0	0	-2.00000	-0.37500	1.89984
0	0	0	0	0	0	2	0	2.00000	-0.23529	1.92597
0	0	-2	0	0	2	0	0	0.00000	-0.22222	1.87248
0	0	0	0	0	0	0	0	0.00000	-0.21053	1.82321
0	-2	0	0	0	0	0	0	-2.00000	-0.30000	1.81934
0	0	0	0	0	0	0	0	0.00000	-0.28571	1.77664
0	0	0	0	0	0	0	2	2.00000	-0.18182	1.79991
0	0	0	2	0	0	-2	0	0.00000	-0.17391	1.76074
0	0	0	0	0	-2	0	0	-2.00000	-0.25000	1.76186
0	0	0	0	0	0	0	0	0.00000	-0.24000	1.72696
0	0	0	-2	0	0	0	0	-2.00000	-0.30769	1.72692
0	0	0	0	0	0	2	0	2.00000	-0.22222	1.74978
0	0	0	0	0	0	0	0	0.00000	-0.21429	1.71874
0	0	0	0	0	0	0	0	0.00000	-0.20690	1.68930
0	0	0	0	-2	0	0	0	-2.00000	-0.26667	1.69181
0	0	0	0	0	0	0	0	0.00000	-0.25806	1.66497
0	-2	0	0	0	0	0	0	-2.00000	-0.31250	1.66654
0	0	0	0	0	0	-2	0	-2.00000	-0.36364	1.66639
0	0	0	2	0	0	0	0	2.00000	-0.29412	1.68958

FIGURE 4.1-19. DATA SAMPLE RATE = 2048 Hz

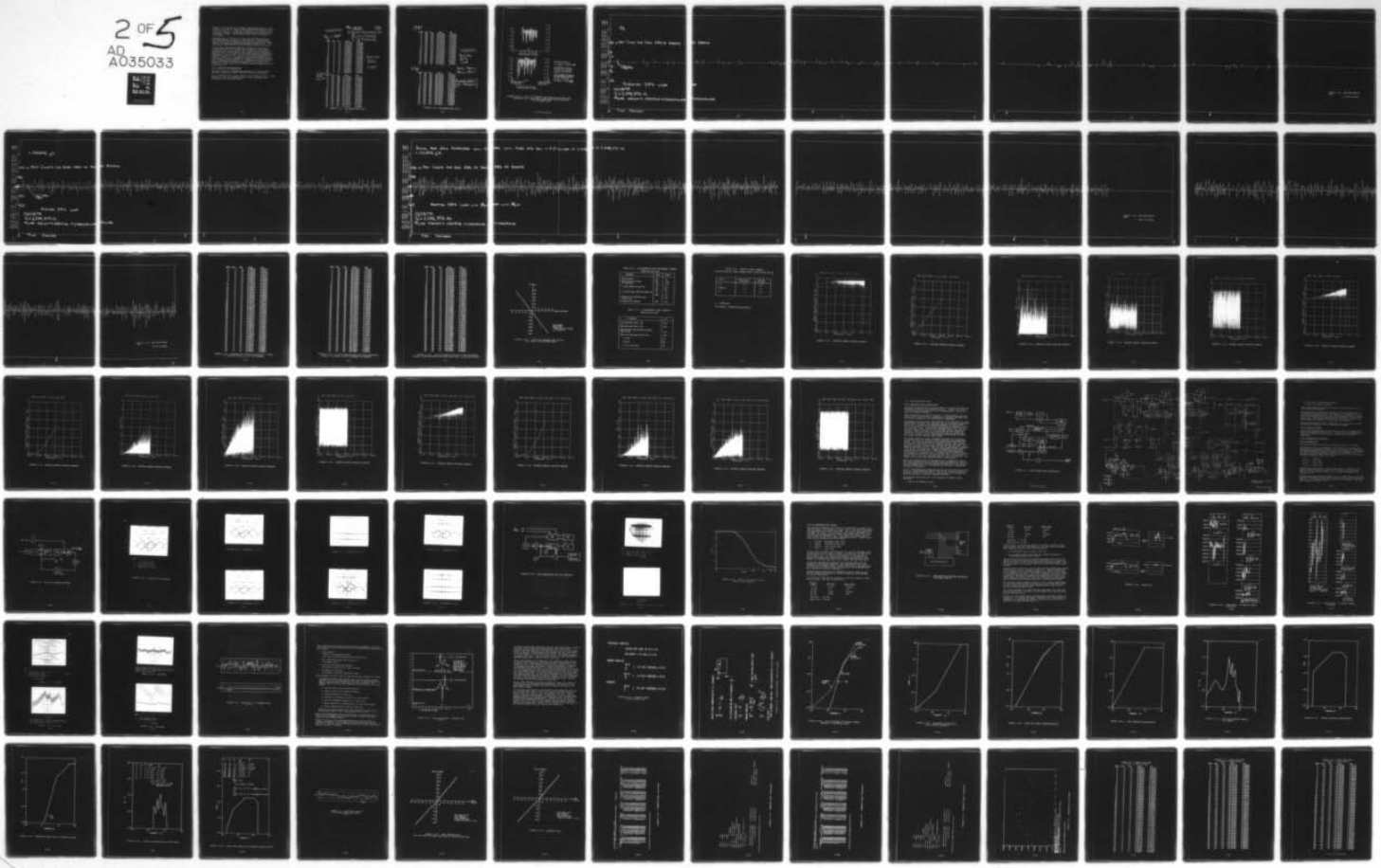
Rf = 4.12K

NET COUNT EACH DITHER CYCLE 1g MEAN: NET COUNT = 51.2								SUM OF COLUMN 1→8 EQUIV TO 256 Hz NET COUNT	RUNNING MEAN OF COLUMN 9	RUNNING STD DEVIATION OF COLUMN 9
1	2	3	4	5	6	7	8	9	10	11
0	1024	54	50							
50	50	50	50	52	52	50	50	404.00000	404.00000	0.00000
52	52	50	52	54	52	50	52	414.00000	409.00000	5.00000
52	52	50	50	52	50	50	50	406.00000	408.00000	4.32049
54	50	50	50	52	52	50	50	408.00000	408.00000	3.74166
52	52	50	52	52	52	50	52	412.00000	408.79999	3.70945
52	52	50	52	52	52	50	52	412.00000	409.32331	3.59011
52	52	50	52	52	52	50	52	412.00000	409.71423	3.45230
52	52	50	52	52	50	50	52	410.00000	409.75000	3.23074
54	52	50	50	52	50	50	52	410.00000	409.77777	3.04696
54	50	50	52	52	54	50	52	414.00000	410.19995	3.15095
52	52	50	52	52	50	50	50	408.00000	410.00000	3.07482
52	52	50	50	52	50	50	52	408.00000	409.83331	2.99537
52	52	50	50	52	50	50	52	408.00000	409.69226	2.91903
52	52	50	52	54	50	50	50	410.00000	409.71423	2.81396
54	50	50	52	52	52	50	50	410.00000	409.73328	2.71948
54	52	50	50	52	52	52	52	414.00000	410.00000	2.80913
52	50	50	50	52	52	50	52	408.00000	409.98232	2.78104
52	52	50	50	52	52	50	52	410.00000	409.98885	2.70573
52	50	50	50	52	52	50	52	408.00000	409.78943	2.66713
52	52	50	50	52	52	50	50	408.00000	409.69995	2.62869
52	52	50	52	52	52	50	52	412.00000	409.80951	2.61168
52	50	50	52	52	50	50	52	408.00000	409.72723	2.57932
52	52	50	52	52	52	50	50	410.00000	409.73907	2.52324
52	52	50	52	52	52	52	52	414.00000	409.91663	2.61274
52	52	50	50	52	50	50	50	406.00000	409.75995	2.67253
52	52	50	52	52	52	50	50	410.00000	409.76923	2.62103
52	52	50	52	52	52	50	52	412.00000	409.85181	2.60631
54	50	50	52	52	50	50	52	410.00000	409.85712	2.55950
52	52	50	50	52	50	50	50	406.00000	409.72412	2.61160
52	52	50	52	52	52	50	52	412.00000	409.79999	2.60000
54	52	50	50	52	52	50	52	412.00000	409.87091	2.58709
54	52	50	52	50	50	50	50	408.00000	409.81250	2.56707
52	50	50	52	52	52	50	52	410.00000	409.81818	2.52808

FIGURE 4.1-20. DATA SAMPLE RATE = 2048 Hz
11/21/75 +1g Tc = 1,048,576 Hz

AD-A035 033 HONEYWELL INC ST PETERSBURG FLA AEROSPACE DIV F/G 17/7
STANDARD PRECISION NAVIGATOR/GEANS MODIFICATIONS FOR EAR MOTION--ETC(U)
NOV 76 D GIONET, P E HALL, S SAMSEL F33615-74-C-1068
UNCLASSIFIED 176-13551 AFAL-TR-76-71 NL

2 OF 5
AD A035033



Figures 4.1-21 and 4.1-22 are typical data samples taken at a 256 Hz rate. The data was taken at four different orientations, 0 g's, -0.052 g's, and +1 g. Since the resolution of this loop is four times that required, the deviation figures must be divided by four to compare to Hypha. The deviation ranges from 0.183 pulse to 0.602 pulse.

Theoretically, the deviation for this loop should min and max 204 times between 1 g and 0 g in one quadrant. To observe and verify the min and max deviation values to be expected, data was taken at one-degree increments and plotted (Figure 4.1-23). This plot gives a good profile of loop performance around null (0 g).

To more fully observe data behavior, the data for one record (1,024 points over four seconds) was plotted on a line printer (Figures 4.1-24, 4.1-25, and 4.1-26). These three conditions are best deviation, worse deviation, and forced one count deviation. Figures 4.1-27, 4.1-28 and 4.1-29 are data typeouts of these same conditions. Figure 4.1-30 is a plot of the null deadband test results. Table 4.1-3 is a summary of the five-day stability test. The linearity test data summary is on Table 4.1-4 and the velocity noise is summarized on Table 4.1-5. Comparisons of this data to Hypha results will be found in Subsection 4.4. Figures 4.1-31 through 4.1-45 are power spectral density analysis results for the three test cases.

4.1.4 Technical Recommendations

The test results of the HRPWM loop indicate it to be a feasible approach to obtaining higher resolution velocity information.

It is recommended that, in the light of the reasons set forth in Subsection 4.4, the final HRPWM concept be used in modifying the SPN/GEANS for the EAR application.

$R_f = 4.12K$ (4B)

11/17/75

256 Hz Data Sample Rate

$\theta_q = 90°$

[1,048,576 Hz Δν Frequency]

RECD	MAX	MIN	MEAN	DEV
1	6	-4	-0.00195	0.93332
2	4	-4	-0.01172	0.80030
3	4	-4	-0.01172	0.81001
4	4	-4	-0.00977	0.79298
5	4	-4	-0.00879	0.91051
6	4	-2	-0.00977	0.82674
7	4	-4	-0.00586	0.77810
8	4	-4	-0.00977	0.79789
9	2	-4	-0.01172	0.80152
10	4	-6	-0.00684	0.88220
11	4	-4	-0.01074	0.88658
12	4	-4	-0.00879	0.80581
13	4	-4	-0.00879	0.81545
14	2	-4	-0.00586	0.76289
15	2	-4	-0.01172	0.72877
16	4	-4	-0.00977	0.81244
17	4	-2	-0.01074	0.73479
18	2	-4	-0.00684	0.77872
19	4	-4	-0.00684	0.75839
20	4	-2	-0.01270	0.75054

Modified SPN Loop

93°

Peak Dev

RECD	MAX	MIN	MEAN	DEV
1	-16	-28	-21.44922	2.42734
2	-16	-28	-21.44336	2.40740
3	-16	-28	-21.44727	2.35583
4	-16	-28	-21.45117	2.40271
5	-16	-30	-21.44531	2.41353
6	-16	-30	-21.44531	2.38094
7	-16	-30	-21.45703	2.43873
8	-16	-30	-21.44922	2.47514
9	-16	-28	-21.45117	2.37984
10	-16	-30	-21.45117	2.48267
11	-16	-30	-21.45117	2.45736
12	-16	-30	-21.45508	2.38565
13	-16	-28	-21.45117	2.39293
14	-16	-30	-21.45703	2.31548
15	-16	-28	-21.44531	2.26663
16	-16	-30	-21.45313	2.44425
17	-16	-30	-21.45313	2.34640
18	-16	-28	-21.45508	2.46617
19	-16	-30	-21.45117	2.33175
20	-16	-30	-21.45508	2.48038

FIGURE 4.1-21. DATA SAMPLE RATE 256 Hz

99°

RECD	MAX	MIN	MEAN	DEV
1	-62	-68	-64.08789	0.64043
2	-60	-68	-64.09180	0.66365
3	-62	-68	-64.08984	0.66732
4	-60	-68	-64.08789	0.65848
5	-62	-68	-64.08984	0.65551
6	-62	-68	-64.08594	0.64952
7	-32	-70	-64.06055	1.21192
8	-62	-68	-64.08789	0.65848
9	-62	-68	-64.08984	0.63122
10	-62	-68	-64.08789	0.72079
11	-62	-68	-64.09180	0.63967
12	-62	-68	-64.08594	0.69034
13	-60	-68	-64.09180	0.68108
14	-60	-70	-64.09180	0.72011
15	-32	-68	-64.05664	1.20586
16	-32	-68	-64.05664	1.19283
17	-62	-68	-64.08984	0.64952
18	-62	-66	-64.08789	0.62187
19	-62	-68	-64.09180	0.69245
20	-60	-68	-64.08984	0.69597

11/17/75

MODIFIED SFN LOOP

+1g

DATA SAMPLE RATE: 256 Hz

RECD	MAX	MIN	MEAN	DEV
1	416	404	409.88477	2.16506
2	416	404	409.88281	2.20794
3	416	404	409.88281	2.12867
4	416	404	409.88672	2.10654
5	416	404	409.87891	2.12867
6	416	404	409.88086	2.10654
7	416	404	409.87891	2.11394
8	416	404	409.89062	2.15783
9	418	404	409.87891	2.09165
10	416	404	409.88281	2.06155
11	416	404	409.88086	2.15058
12	416	404	409.88086	2.08417
13	416	404	409.88086	2.00780
14	416	404	409.87891	2.00780
15	416	404	409.88281	2.00000
16	416	404	409.87891	1.92841
17	416	404	409.8828.	2.06912
18	416	406	409.88281	2.00000
19	414	404	409.88477	1.85405
20	416	404	409.88477	1.92841

[1,048,576 Hz ΔV FREQUENCY]

FIGURE 4.1-22. DATA SAMPLE RATE 256 Hz

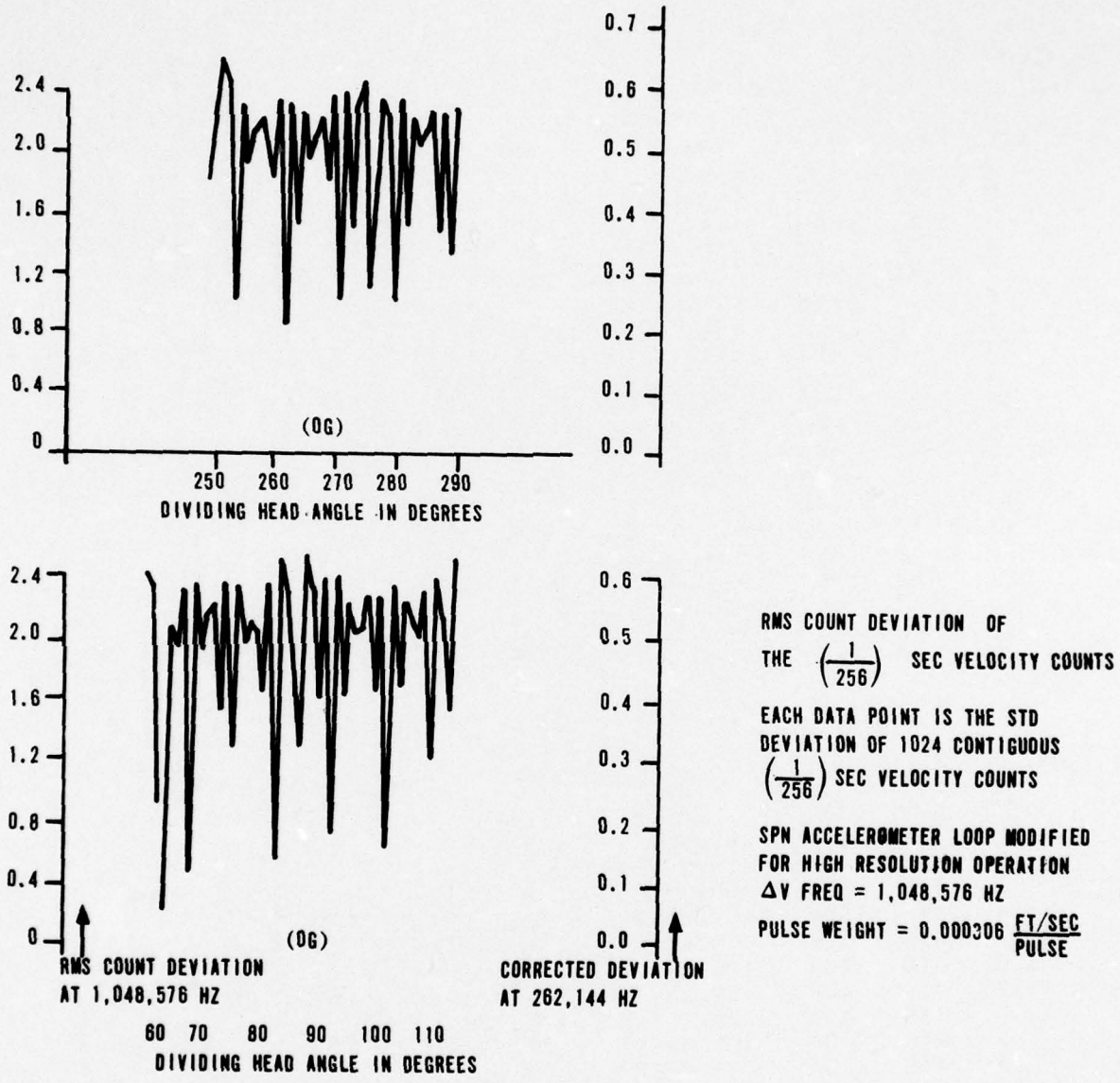


FIGURE 4.1-23. 11/17/75 LINEARITY RUN MODIFIED SPN LOOP HIGH RESOLUTION DIV. HEAD ANGLE VERSUS RMS COUNT DEVIATION 256 Hz SAMPLE RATE

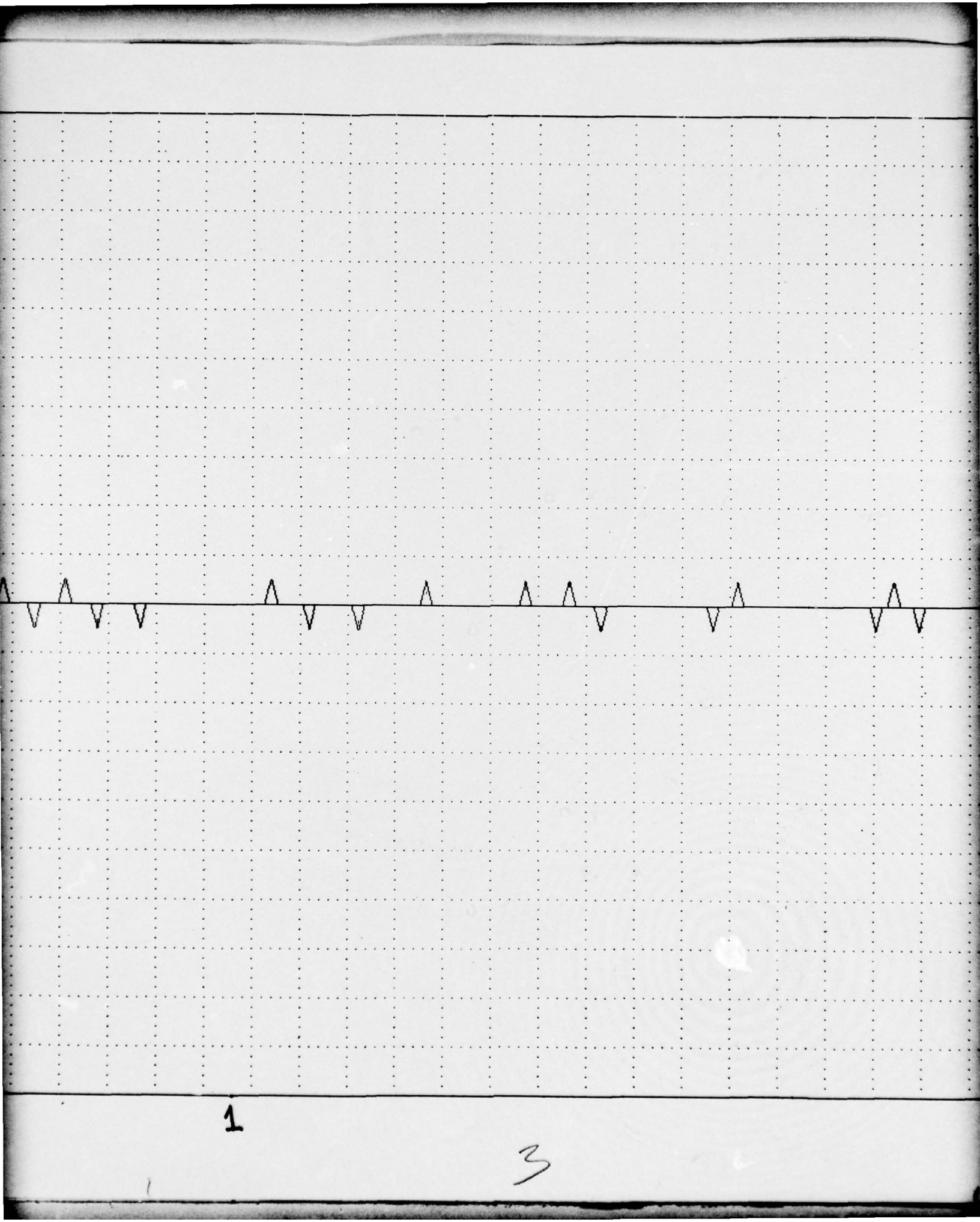
SOLID LINE - VARIABLE 2, BIAS = 0.00000, OPERATION - VARIABLE 0, VERTICAL SCALE (PER INCH) = 0.00000
DOTTED LINE - VARIABLE 31, BIAS = 0.00000, OPERATION - VARIABLE 0, VERTICAL SCALE (PER INCH) = 1.00000
DASHED LINE - VARIABLE 31, BIAS = 0.00000, OPERATION - VARIABLE 0, VERTICAL SCALE (PER INCH) = 1.00000
START TIME = 0.00 STOP TIME = 4.00 HORIZONTAL SCALE (PER INCH) = 0.06
Oq
+16
← NET COUNT FOR EACH 256 Hz SAMPLE
+8
+4
0
-4
-8
-16
$\left(\frac{2}{256}\right)$ SEC
MODIFIED SPN LOOP
11/18/75
T_c = 1,048,576 Hz
PULSE WEIGHT = .000306 FT/SEC/PULSE
0
TIME: SECONDS

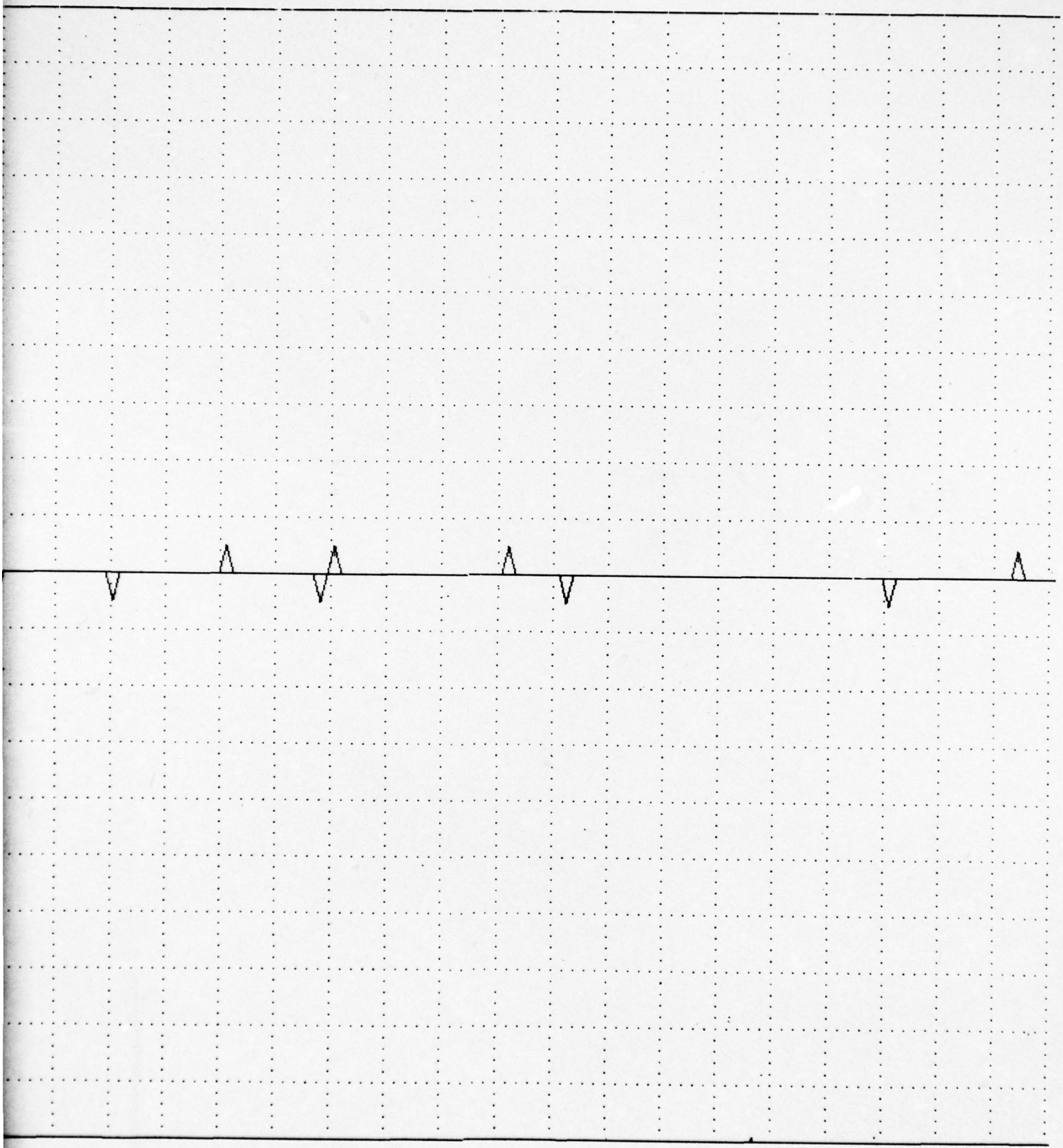
HE SAMPLE

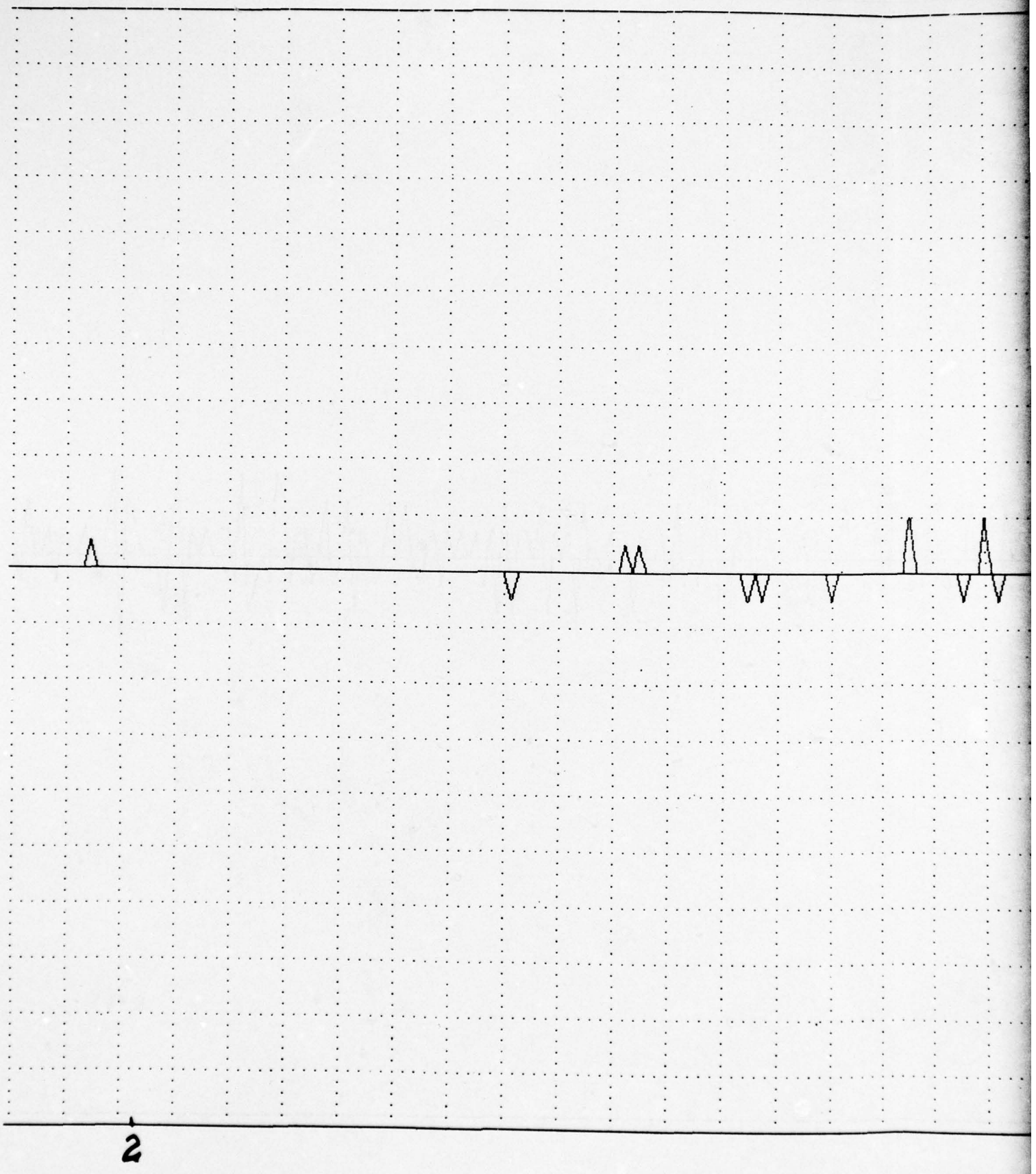


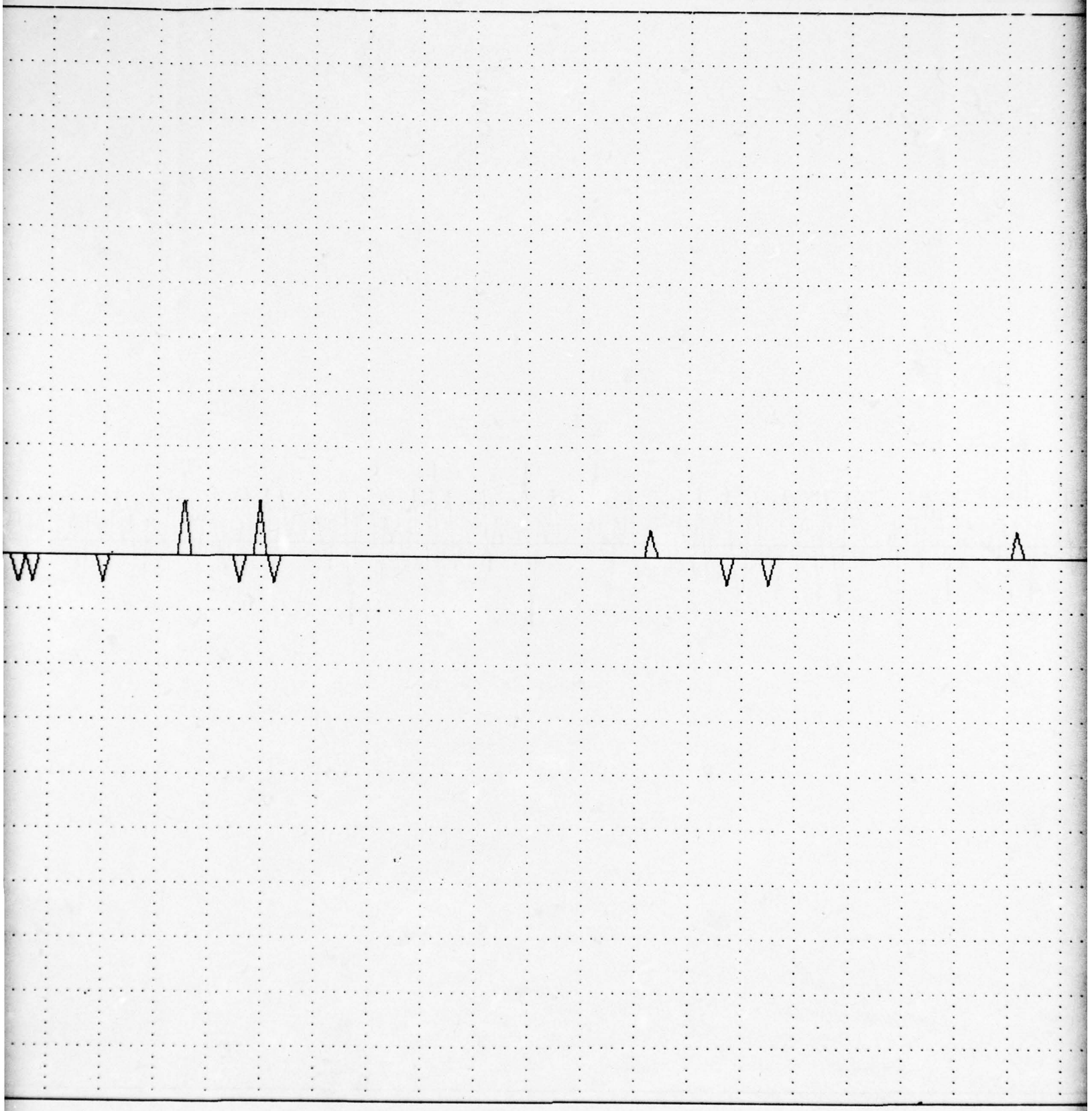
OP

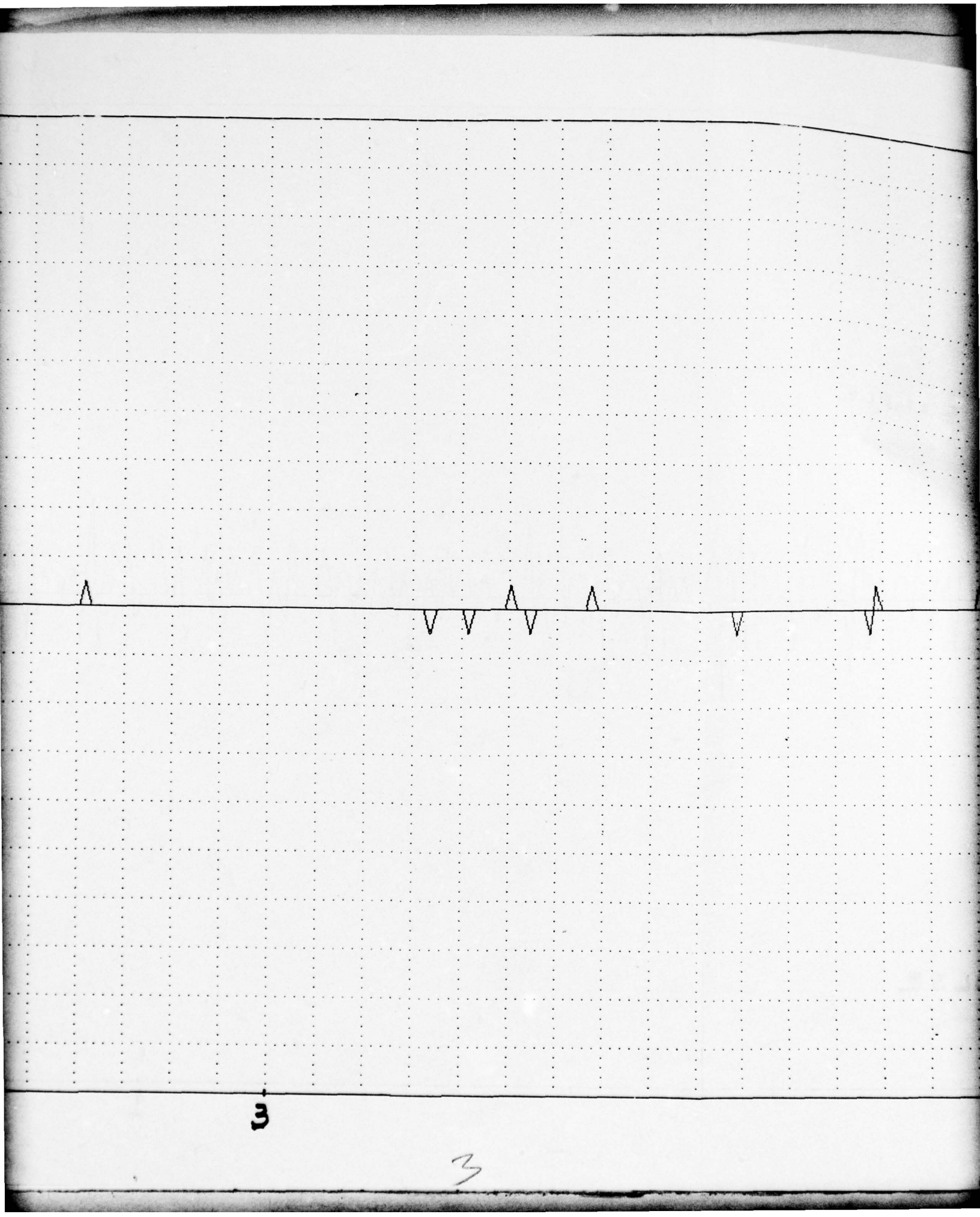
FT/SEC/PULSE


1
3




2




3

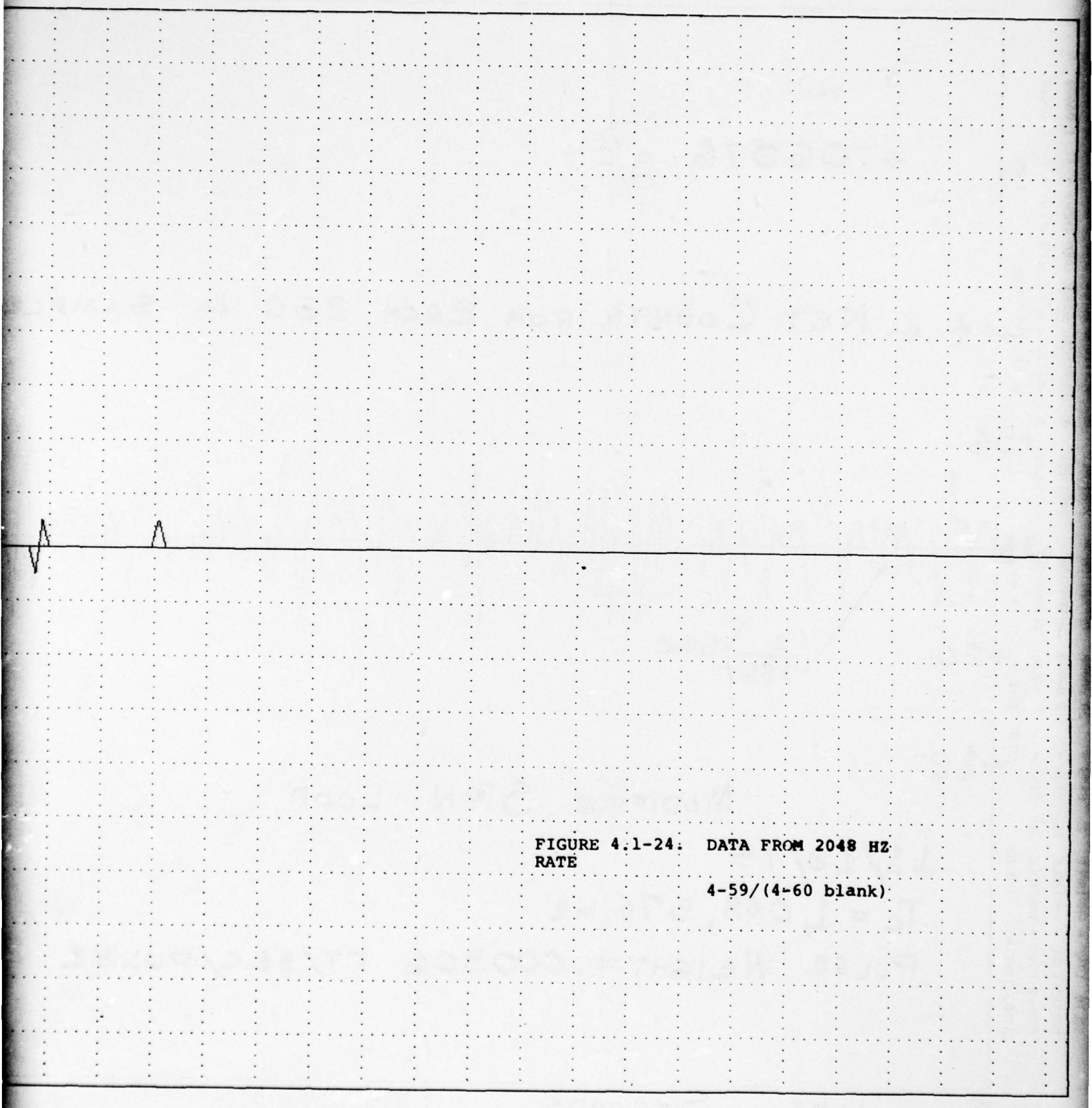


FIGURE 4.1-24. DATA FROM 2048 HZ RATE

SOLID LINE - VARIABLE 2. BIAS - 20.00000, OPERATION = VARIABLE 0, VERTICAL SCALE (PER INCH) - 0.00000
DOTTED LINE - VARIABLE 31. BIAS - 0.00000, OPERATION = VARIABLE 0, VERTICAL SCALE (PER INCH) - 1.00000
DASHED LINE - VARIABLE 31. BIAS - 0.00000, OPERATION = VARIABLE 0, VERTICAL SCALE (PER INCH) - 1.00000
START TIME = .0.00 STOP TIME = 4.00 SCALE (PER INCH) = 0.06

+.06976 g's

+44 ← NET COUNTS FOR EACH 256 Hz SA

+36

+28

+20

+12

$\left(\frac{2}{256}\right)$ SEC

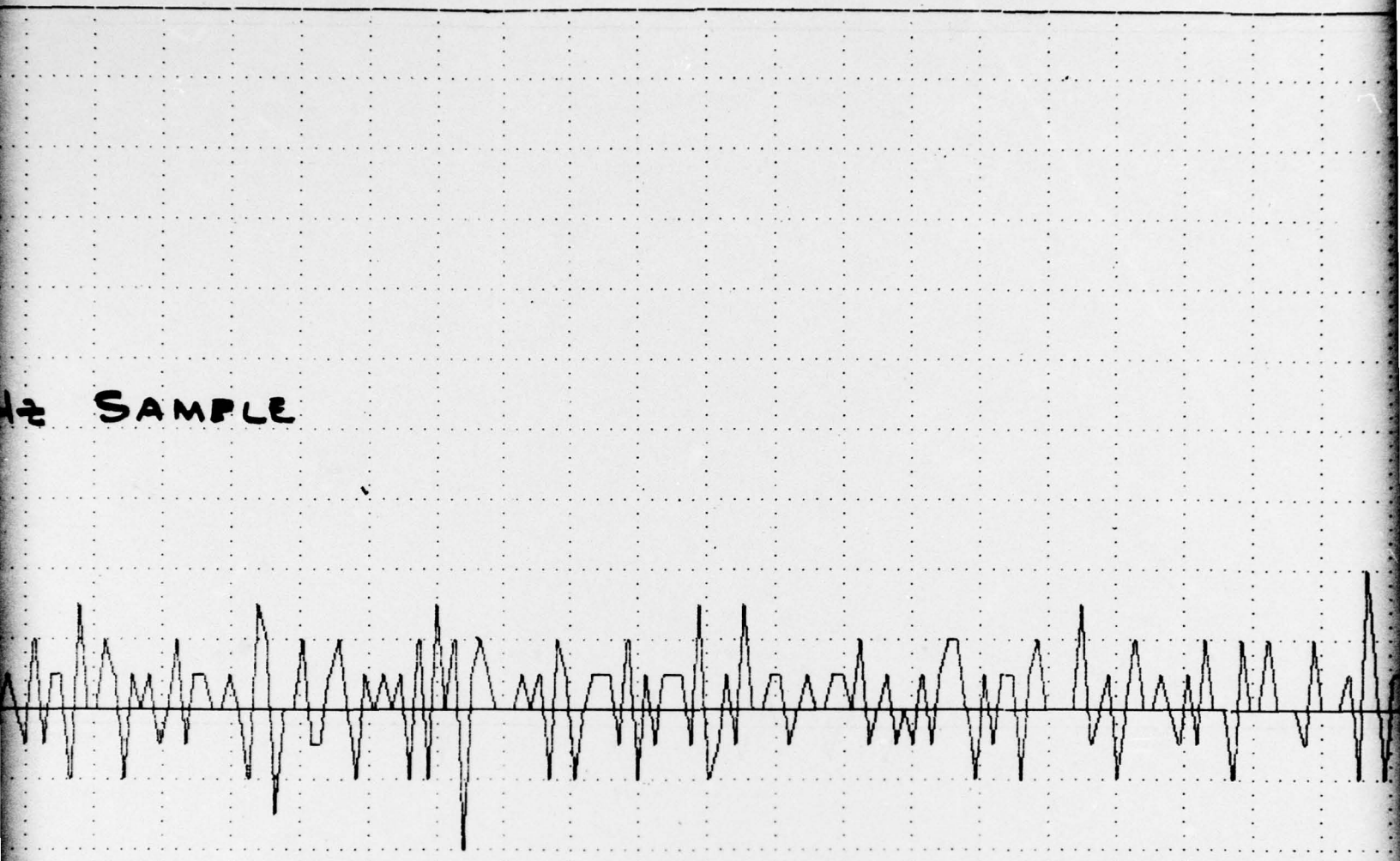
MODIFIED SPN LOOP

11/18/75

$T_c = 1,048,576$ Hz

PULSE WEIGHT = .000306 FT/SEC/PULS

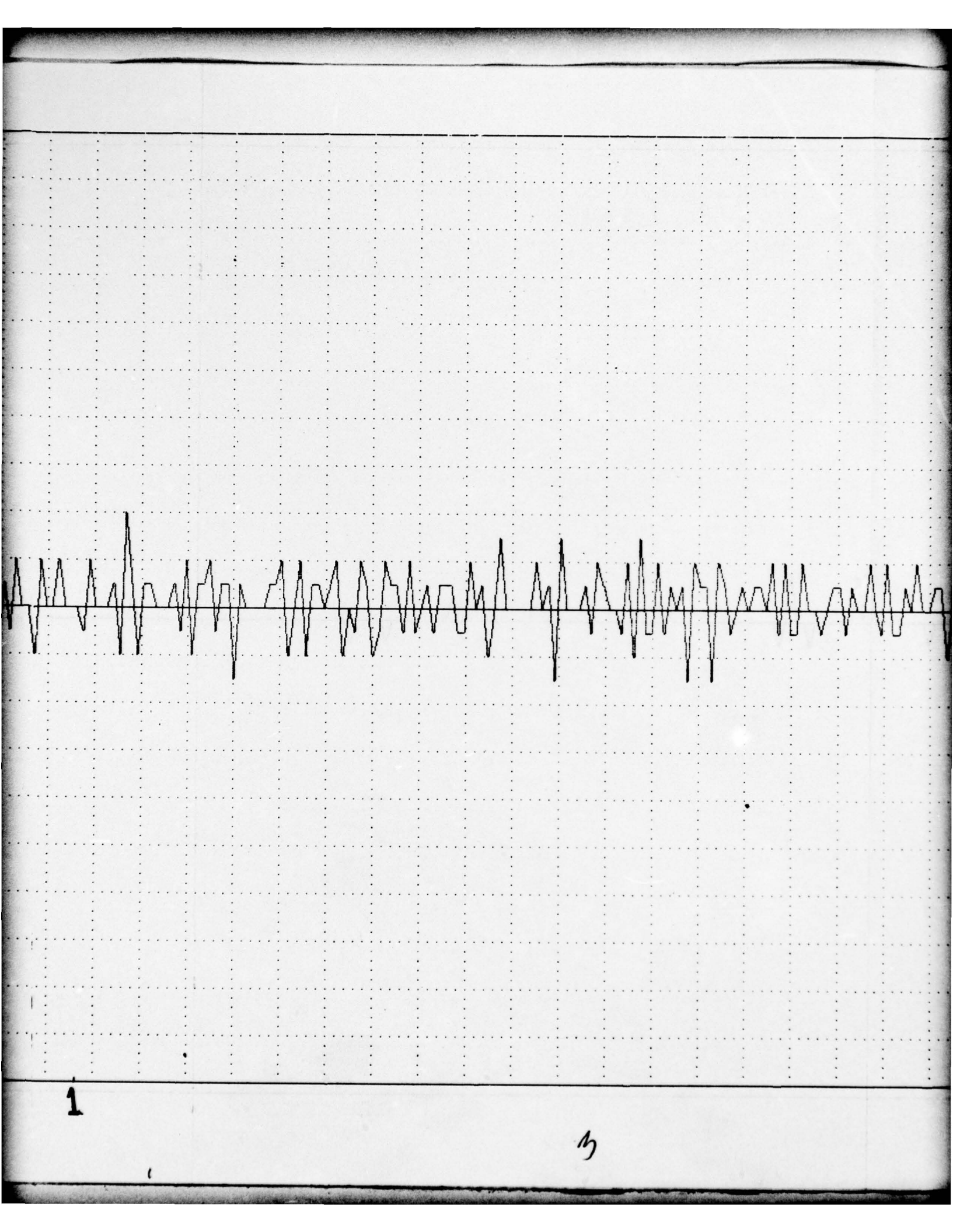
0 TIME: SECONDS

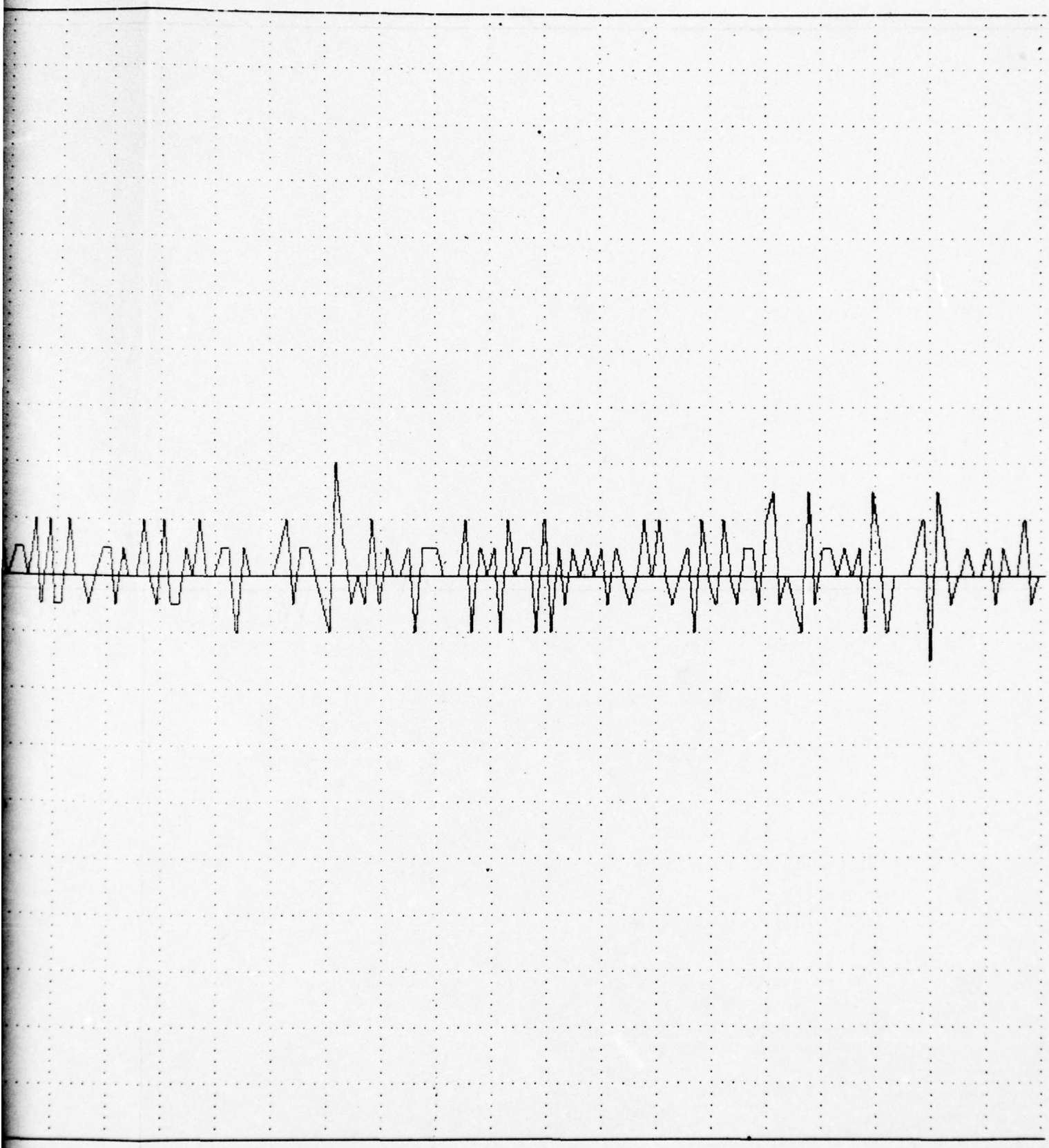


/PULSE

1

2


1



SOLID LINE - VARIABLE 2, BIAS - 20.00000, OPERATION - VARIABLE 0, VERTICAL SCALE (PER INCH) - 0.00000
DOTTED LINE - VARIABLE 31, BIAS - 1.00000, OPERATION - VARIABLE 0, VERTICAL SCALE (PER INCH) - 1.00000
DASHED LINE - VARIABLE 31, BIAS - 1.00000, OPERATION - VARIABLE 0, VERTICAL SCALE (PER INCH) - 1.00000
START TIME - 0.00 STOP TIME - 4.00 HORIZONTAL SCALE (PER INCH) - 0.05

SIGNAL AMP GAIN INCREASED UNTIL 4
+.06976 g's

+44 ← NET COUNTS FOR EACH 256 Hz SAM

+36

+28

+20

+12

MODIFIED SPN LOOP WITH R_f

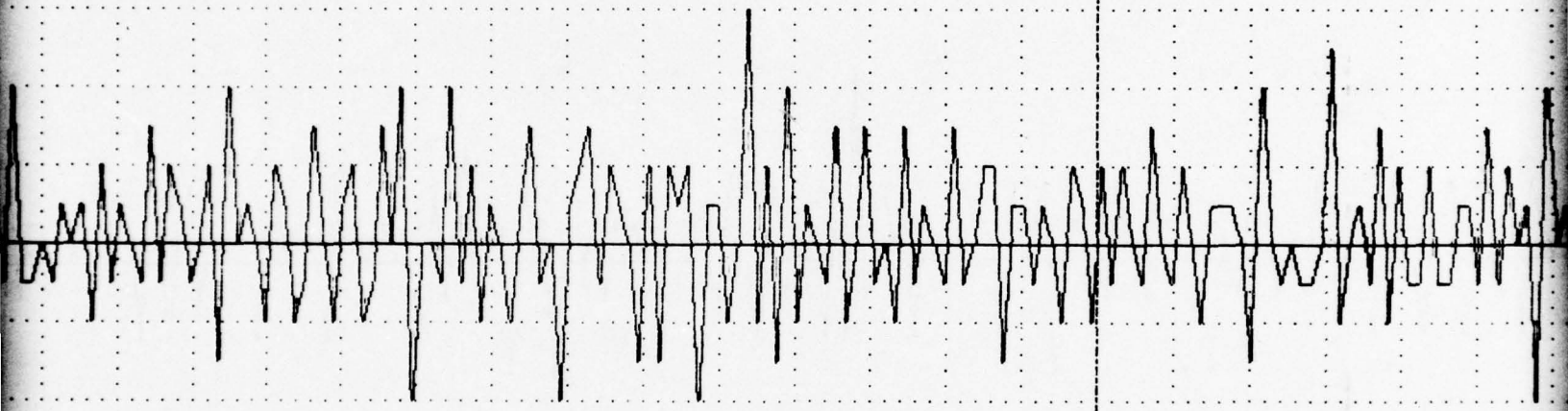
11/18/75
$T_c = 1,048,576$ Hz
PULSE WEIGHT = .000306 FT/SEC/PULSE

0 TIME: SECONDS

1

SED UNTIL 4 SEC STD. DEV. = 4.0 PULSES AT 1,048

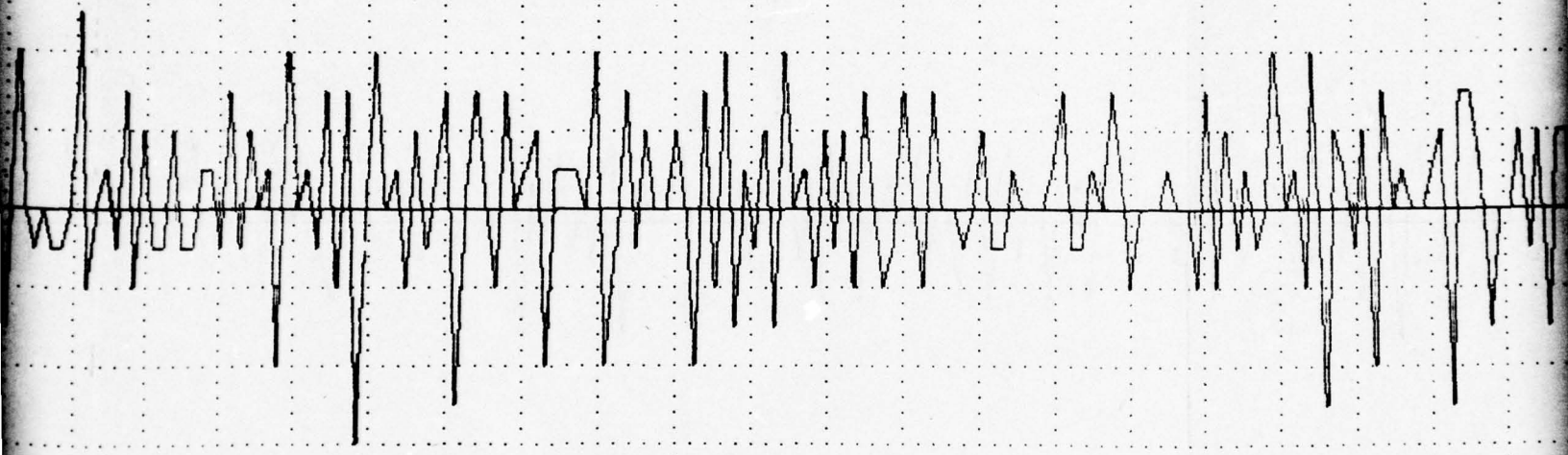
256 Hz SAMPLE



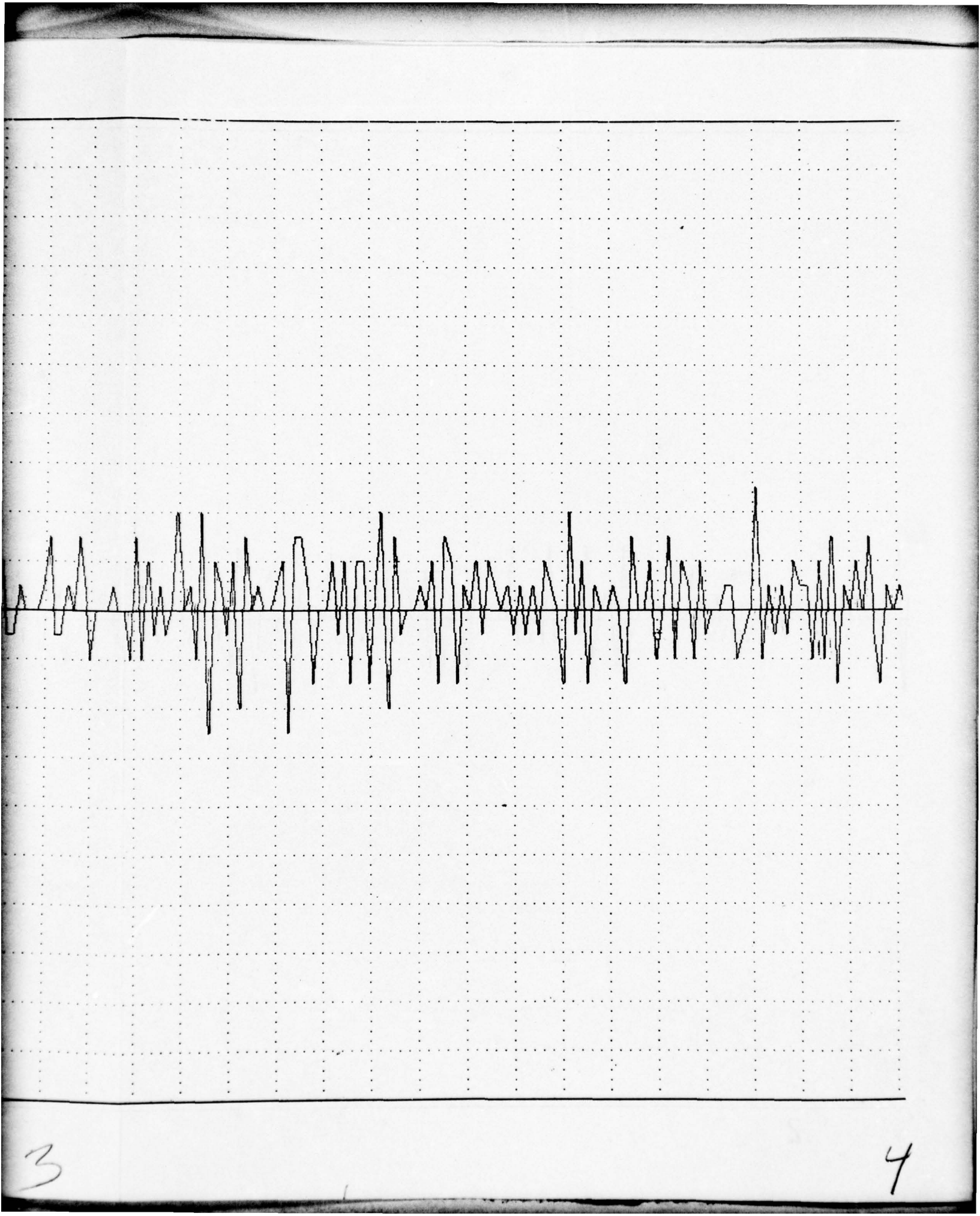
OOP WITH R_f =

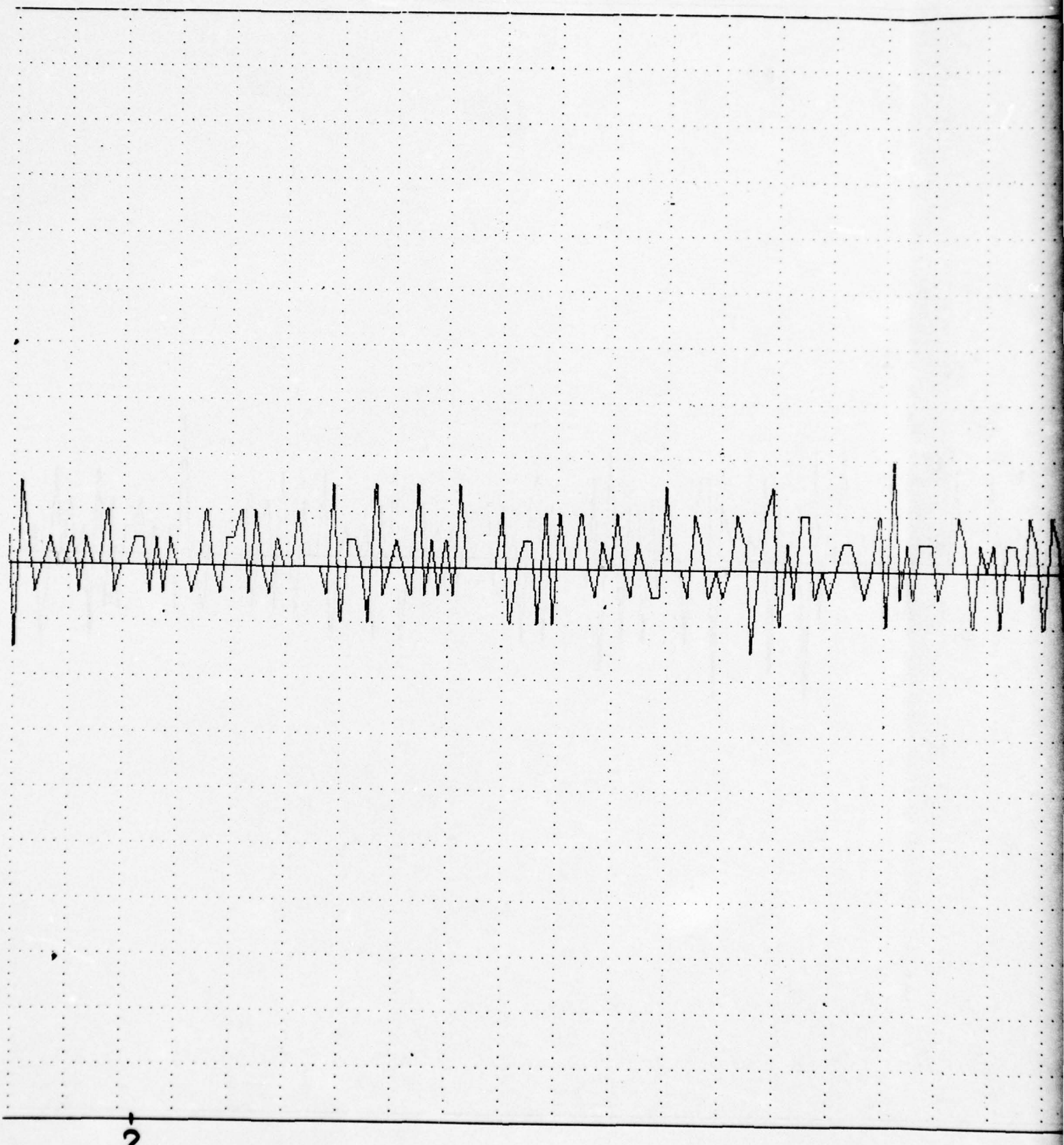
FT/SEC/PULSE

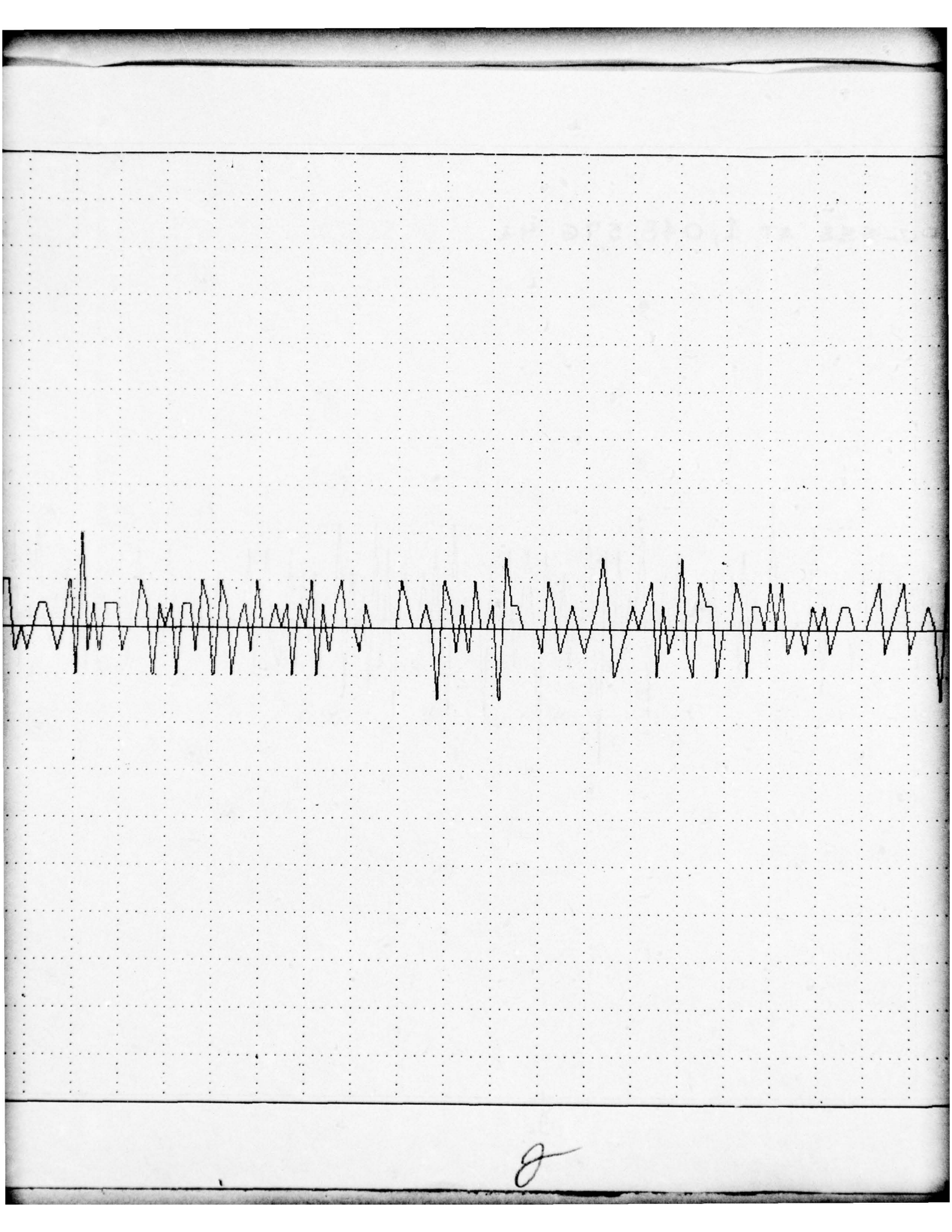
AT 1,048,576 Hz



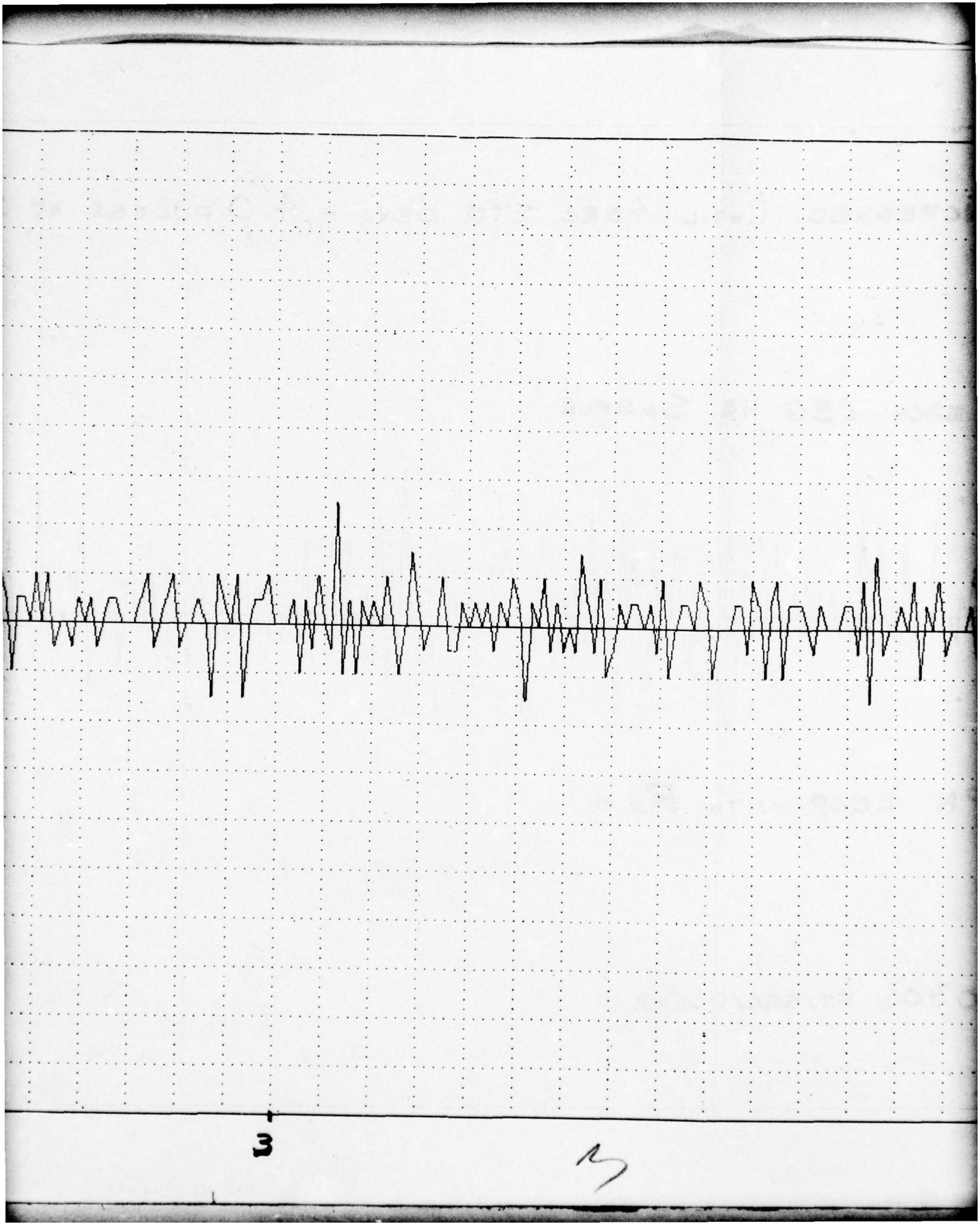
1




2
1



8


3

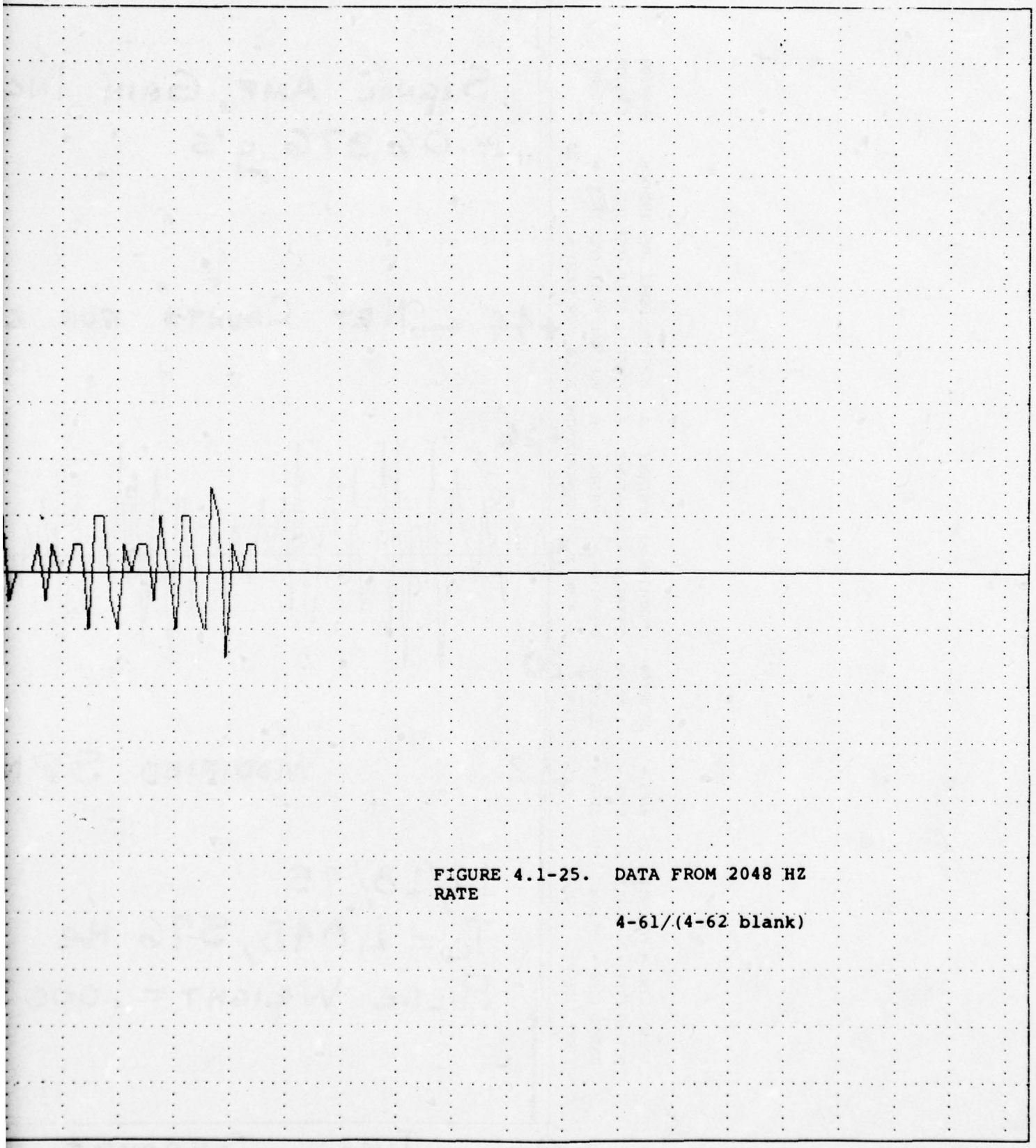
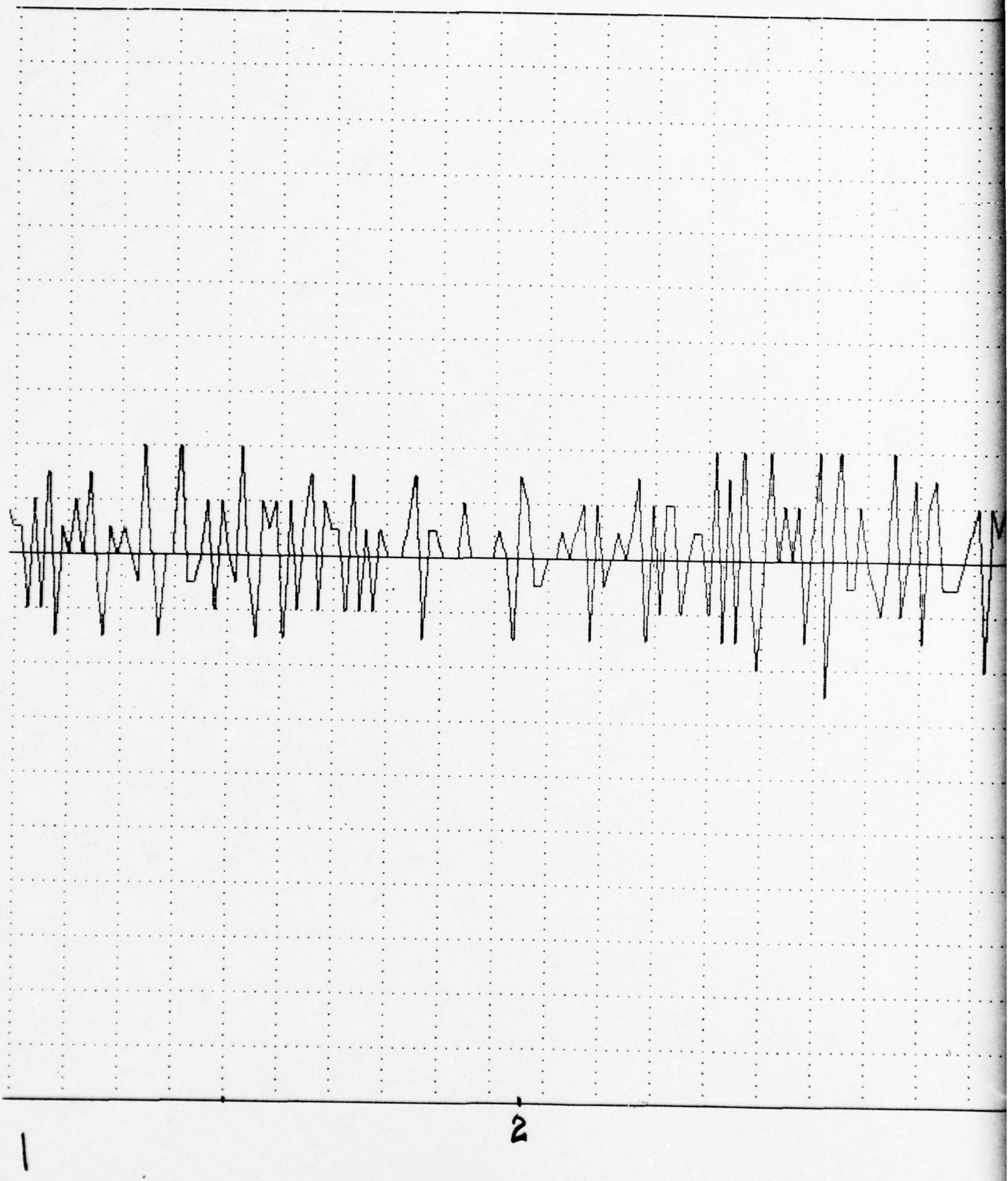
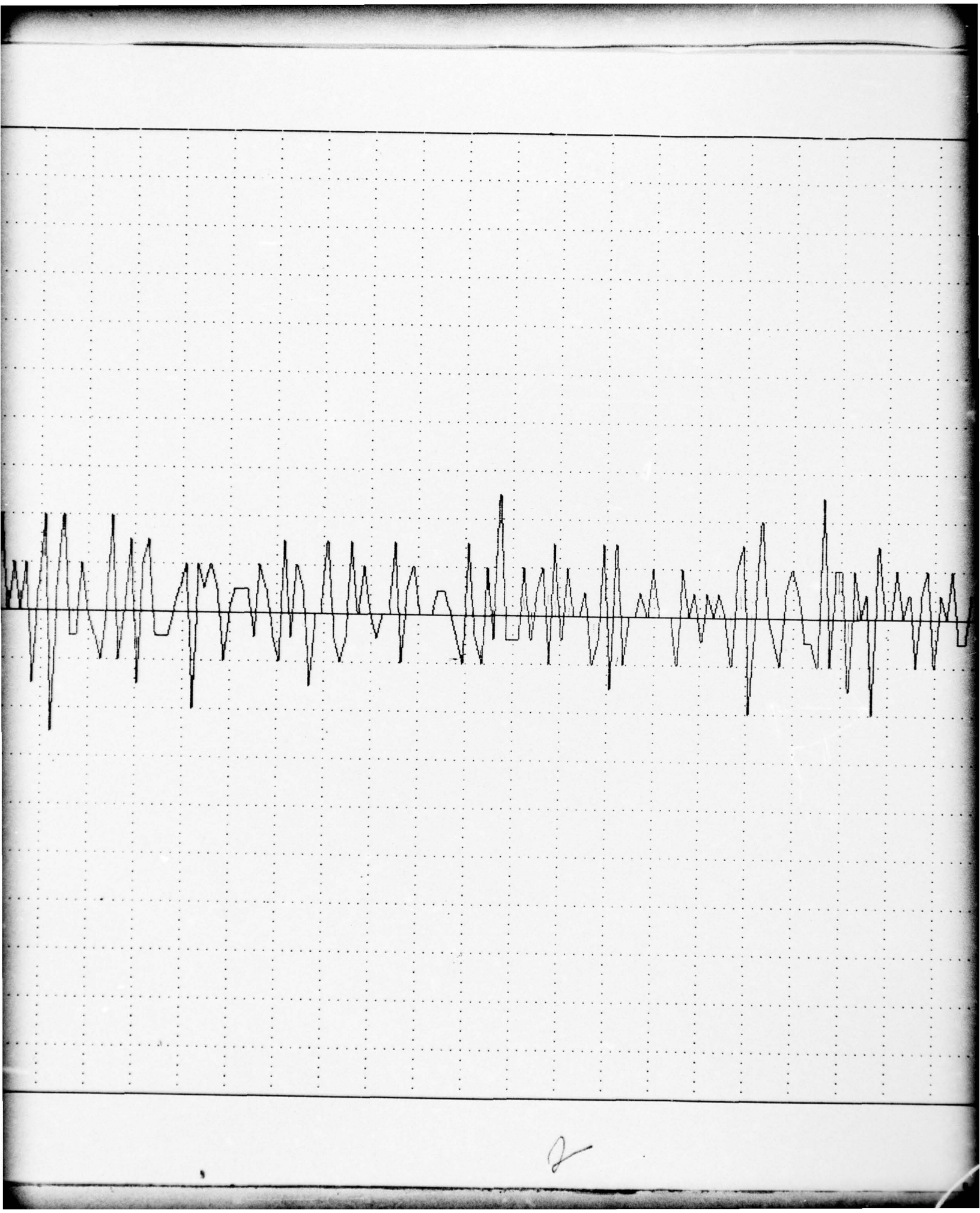
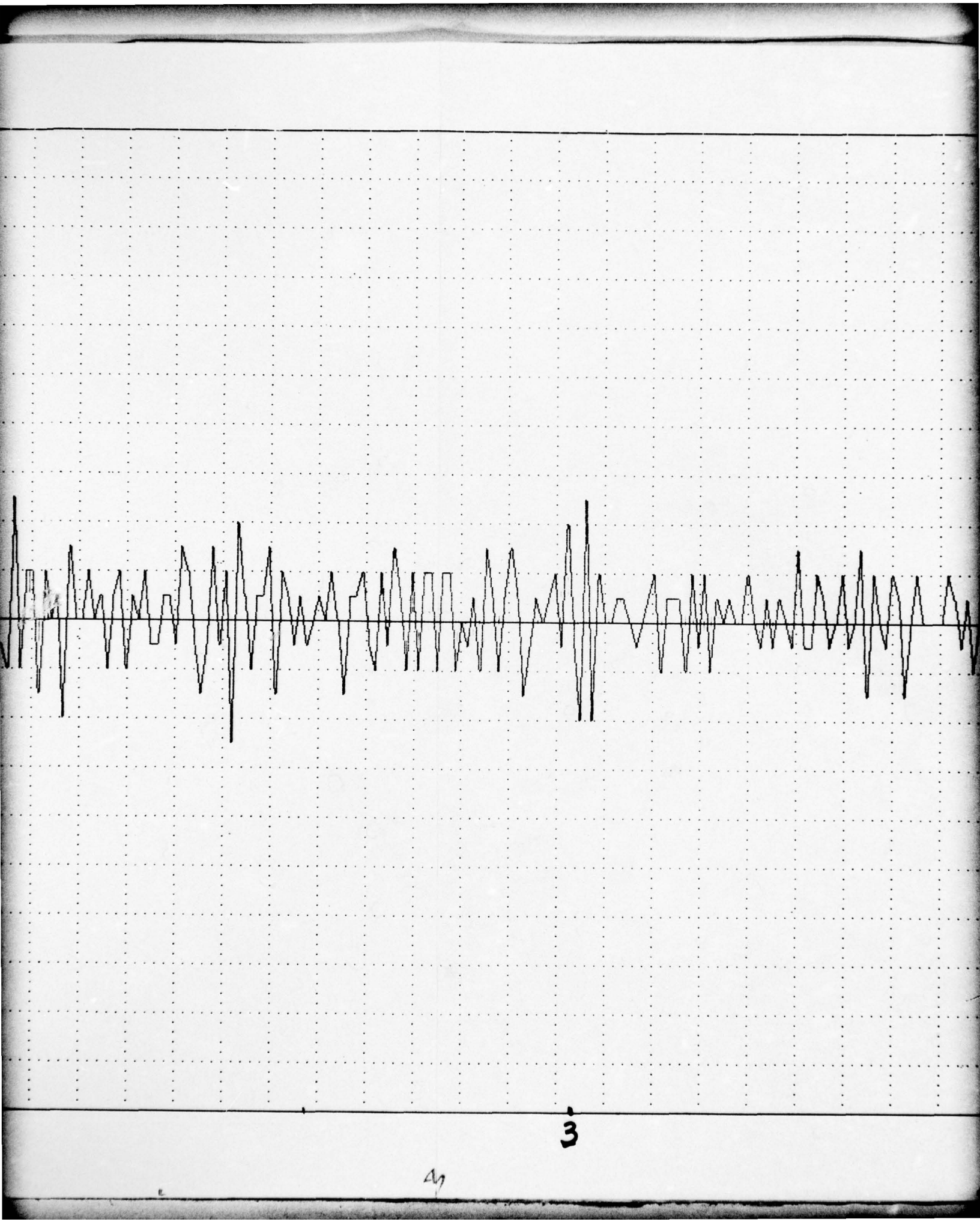


FIGURE 4.1-25. DATA FROM 2048 HZ RATE

4-61/(4-62 blank)


1
2




3

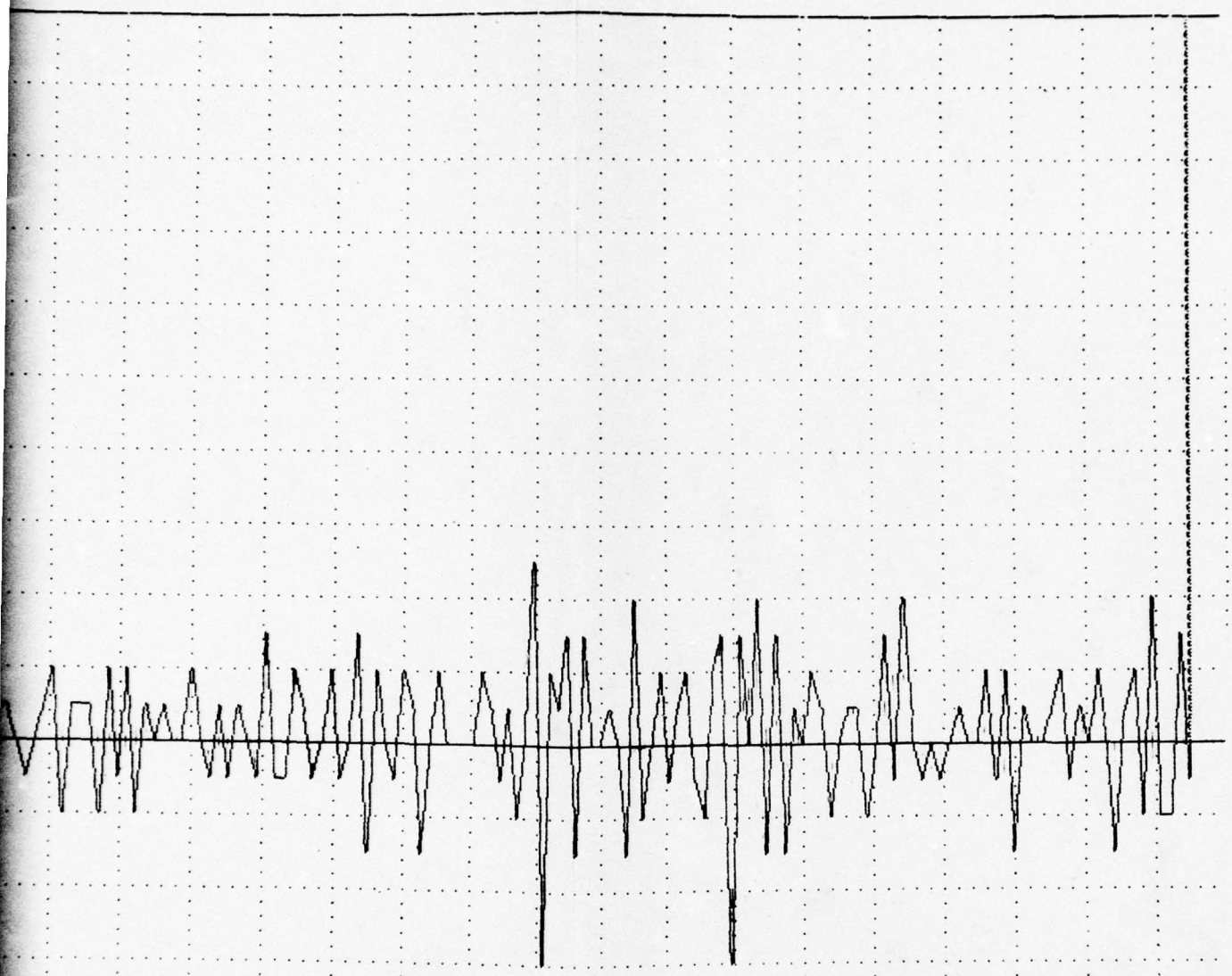


FIGURE 4.1-26. DATA FROM 20448 HZ RATE

4-63/(4-64 blank)

RECD	MAX	MIN	MEAN	DEV
1	4	-4	-0.00781	0.57277
2	4	-2	-0.01172	0.63111
3	2	-2	-0.00391	0.57959
4	2	-4	-0.00977	0.53391
5	2	-2	-0.00781	0.55193
6	2	-4	-0.00977	0.57614
7	4	-2	-0.00977	0.62804
8	4	-2	-0.00781	0.57955
9	2	-2	-0.00781	0.55896
10	2	-4	-0.01172	0.57270
11	4	-4	-0.00586	0.58959
12	4	-2	-0.00977	0.55543
13	2	-4	-0.00977	0.64036
14	4	-4	-0.00781	0.61867
15	2	-4	-0.00977	0.56932
16	2	-4	-0.00586	0.62809
17	2	-2	-0.00977	0.56242
18	4	-4	-0.00586	0.60915
19	4	-2	-0.01367	0.58280
20	2	-4	-0.00781	0.63117
21	2	-4	-0.00781	0.59288
22	2	-4	-0.01172	0.63727
23	2	-2	-0.00586	0.54840
24	2	-2	-0.00977	0.53391
25	2	-4	-0.00781	0.59943
26	2	-2	-0.00781	0.59288
27	2	-2	-0.01172	0.59936
28	2	-2	-0.00781	0.55193
29	2	-2	-0.00781	0.57955
30	2	-4	-0.00977	0.58954
31	2	-4	-0.00781	0.56591
32	2	-4	-0.00977	0.58288
33	2	-2	-0.00781	0.62495
34	2	-2	-0.00586	0.62184
35	2	-4	-0.00977	0.60265
36	4	-4	-0.00977	0.60910
37	4	-2	-0.01172	0.59281
38	2	-2	-0.00781	0.49994
39	2	-4	-0.00586	0.58293
40	4	-2	-0.00977	0.56932
41	4	-4	-0.00977	0.60265
42	4	-2	-0.00977	0.64036
43	2	-2	-0.01172	0.54474
44	2	-2	-0.00391	0.53763
45	4	-2	-0.00781	0.57955
46	4	-4	-0.00977	0.60265
47	4	-2	-0.00977	0.58288
48	2	-4	-0.00781	0.60591
49	2	-4	-0.00977	0.62804

FIGURE 4.1-27. MODIFIED SPN LOOP HIGH RESOLUTION 1 PULSE = 0.0003125 FT/SEC Og (90°) 200 RECORDS

RECD	MAX	MIN	MEAN	DEV
1	38	20	28.55859	2.67666
2	36	20	28.56836	2.65335
3	36	22	28.56836	2.58625
4	36	22	28.56055	2.57585
5	38	22	28.56836	2.67826
6	38	20	28.56641	2.72422
7	38	22	28.56055	2.52221
8	36	22	28.56836	2.70149
9	36	20	28.56250	2.64501
10	36	22	28.56055	2.59850
11	38	22	28.56445	2.74818
12	36	22	28.56641	2.52787
13	38	22	28.56641	2.70407
14	36	20	28.56445	2.62309
15	36	20	28.56641	2.70984
16	36	22	28.56055	2.68718
17	36	20	28.56250	2.74218
18	38	20	28.56250	2.64649
19	36	20	28.57227	2.55499
20	38	20	28.56250	2.72646
21	38	22	28.56641	2.62193
22	38	20	28.56445	2.72964
23	36	20	28.56055	2.57282
24	36	20	28.56250	2.68895
25	36	20	28.57031	2.72053
26	38	22	28.56055	2.60000
27	36	22	28.56250	2.73504
28	36	20	28.56445	2.54908
29	38	20	28.56445	2.56740
30	36	20	28.56055	2.70457
31	38	20	28.56836	2.77285
32	36	22	28.56055	2.68427
33	38	22	28.57031	2.63446
34	38	20	28.56250	2.71498
35	38	20	28.56445	2.73250
36	36	20	28.57031	2.57295
37	38	22	28.55664	2.53081
38	36	22	28.56836	2.59078
39	38	22	28.56250	2.64058
40	38	20	28.56641	2.67210
41	38	20	28.56445	2.67178
42	38	20	28.56250	2.65386
43	36	22	28.56445	2.62160
44	36	20	28.56250	2.77756
45	38	22	28.56836	2.76155
46	36	20	28.55859	2.72153
47	38	20	28.57031	2.68585
48	38	20	28.56250	2.62872
49	36	20	28.56055	2.61349

FIGURE 4.1-28. 11/18/75 MODIFIED SPN LOOP HIGH RESOLUTION
1 PULSE = 0.0003125 FT/SEC 86 DEGREES 200 RECORDS

RECD	MAX	MIN	MEAN	DEV
1	40	16	28.54297	3.94321
2	42	16	28.55273	4.09401
3	42	16	28.55273	4.06624
4	40	16	28.54102	3.92909
5	44	16	28.54883	4.02332
6	40	14	28.55078	4.14311
7	42	16	28.54883	4.12779
8	44	16	28.55469	4.32798
9	40	16	28.54297	3.98656
10	40	16	28.55273	3.97884
11	42	18	28.54688	4.01240
12	42	16	28.54688	3.99093
13	42	16	28.54492	4.13398
14	40	16	28.54883	4.02137
15	42	16	28.55273	3.83283
16	40	12	28.54492	4.03645
17	42	18	28.55469	4.12653
18	40	14	28.55273	4.01403
19	40	16	28.54492	4.06441
20	42	16	28.55078	4.04677
21	40	14	28.54492	4.24033
22	42	12	28.55273	4.18833
23	44	14	28.54883	3.80475
24	40	16	28.54883	4.11262
25	40	16	28.54883	3.97742
26	40	16	28.54688	3.92579
27	42	16	28.55469	4.16610
28	42	16	28.54492	4.08455
29	42	16	28.54688	4.10289
30	40	14	28.55469	4.13599
31	40	16	28.54297	4.30685
32	40	16	28.55078	4.03129
33	40	18	28.56055	4.26219
34	40	16	28.54297	4.06612
35	42	16	28.54688	4.01337
36	40	18	28.54883	3.78416
37	40	16	28.56055	4.21333
38	42	12	28.54688	4.20817
39	44	16	28.54688	4.18770
40	42	18	28.54883	4.05137
41	44	16	28.55273	4.09687
42	42	16	28.54297	4.27864
43	40	14	28.55273	4.16683
44	40	14	28.55273	4.05566
45	42	14	28.54688	4.09908
46	42	16	28.55078	4.00212
47	42	18	28.54297	3.95607
48	40	16	28.55859	4.18149
49	40	14	28.54492	4.20239

FIGURE 4.1-29. 11/18/75 MODIFIED SPN LOOP, HIGH RESOLUTION FORCED 1 PULSE DEVIATION FOR WORST CASE SPEC, 86 DEG 200 RECORDS

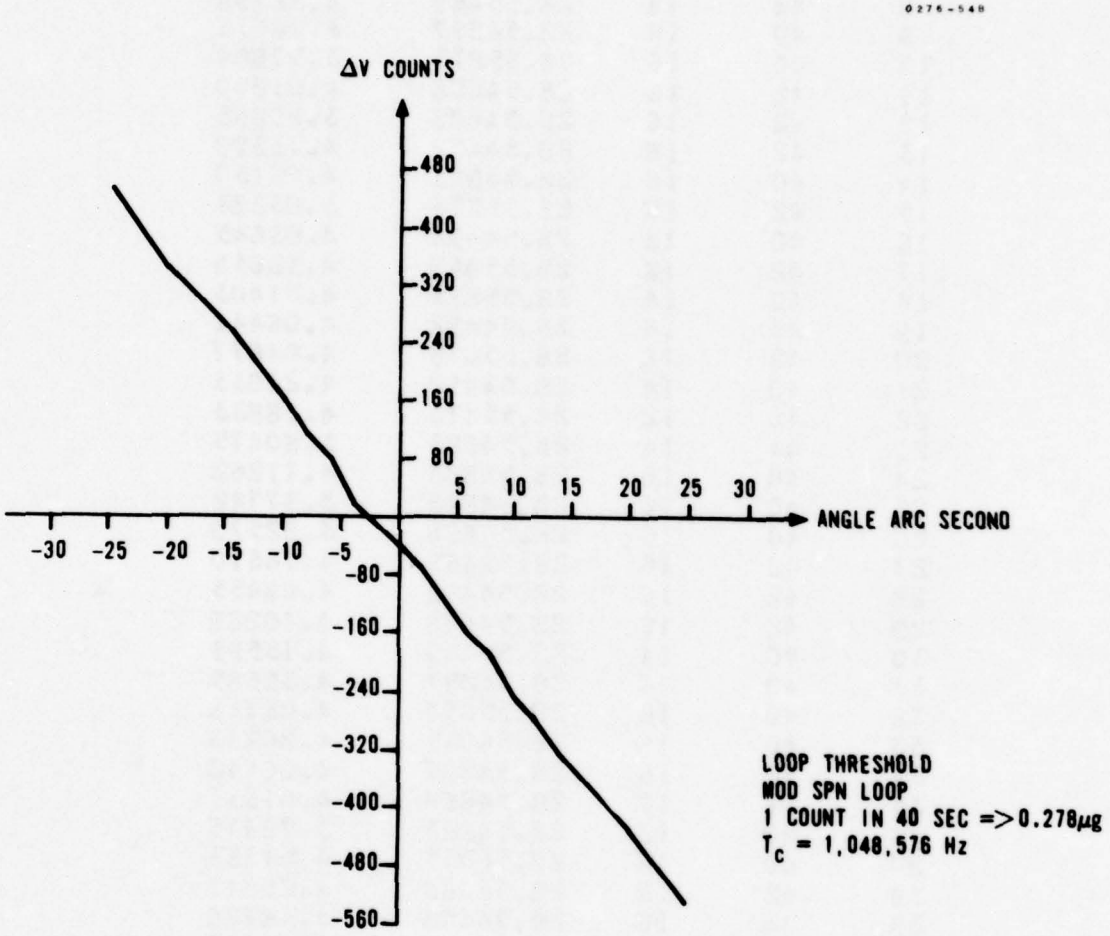


FIGURE 4.1-30. 11/21/75 NULL DEADBAND, MODIFIED SPN LOOP, LOPHA II 40 SEC COUNT TIME

TABLE 4.1-3. ACCELEROMETER LOOP PERFORMANCE SUMMARY
MODIFIED SPN LOOP

Parameter	Cond	Value
Velocity Noise	Min	0.2
Equiv Std Dev in Pulses at 262,144 Hz	Max	0.65
	Avg	0.35
1 g Bias Stability (μg) rms	CD	21.1
	NCD	21.6
1 g Scale Factor Stability (ppm) rms	CD	5.7
	NCD	9.9
Linearity: Std Deviation (μg) from a line		-16.8
Threshold (arc-second)	Max	<0.5

TABLE 4.1-4. ACCELEROMETER LOOP LINEARITY
MODIFIED SPN LOOP

Parameter	μg
Peak Deviation from a line	-51.4
Mean Deviation from a line	-16.8
RMS Deviation from the Mean Deviation from a line	23.6
RMS of the Deviations from a line	29.0
1 g bias	-517
0 g bias	-543
Δ (1 g → 0 g) bias	-26

TABLE 4.1-5. VELOCITY NOISE SUMMARY
(1/256 SECOND NET COUNT SUMMARY OVER A FOUR-SECOND PERIOD)

Input	Count Spread (Pulses)	Std Dev (Pulses)
0 g	± 4	0.8
0.06976 g	± 8	2.7
1 g	± 7	2.4

T_c = 1,048,576 Hz

Pulse Weight = 0.000306 Foot/second/pulse

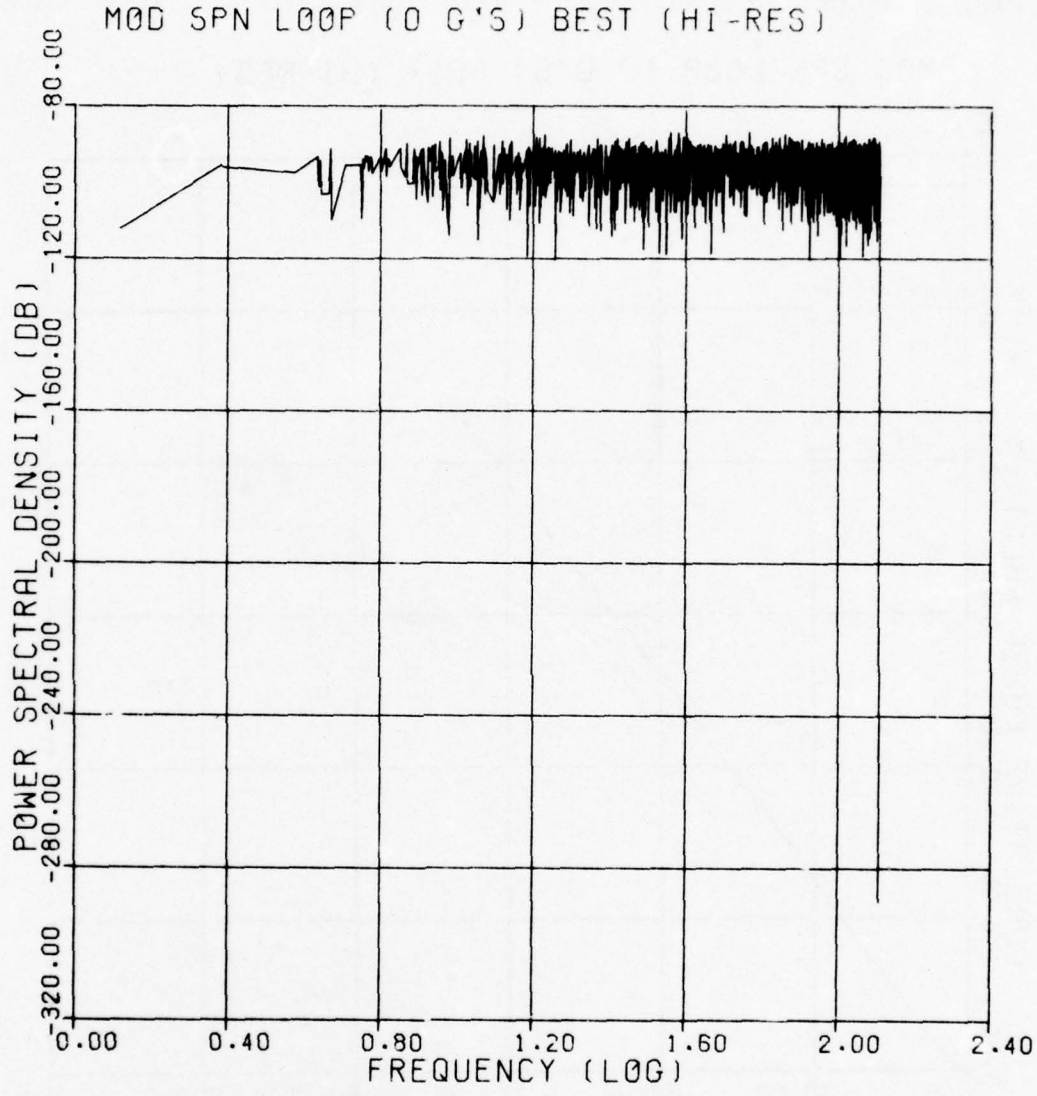


FIGURE 4.1-31. SPECTRAL DENSITY ANALYSIS RESULTS

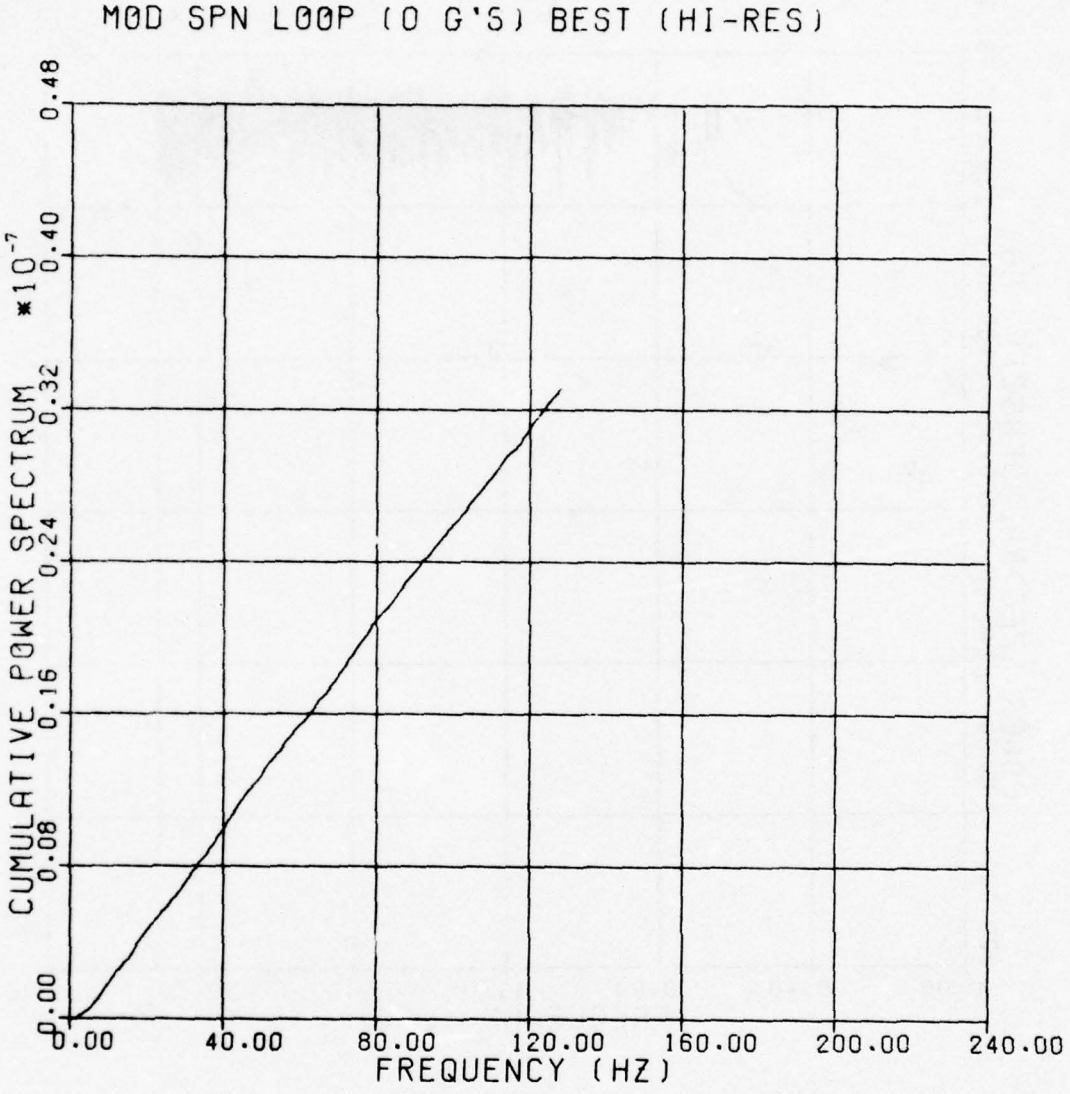


FIGURE 4.1-32. SPECTRAL DENSITY ANALYSIS RESULTS

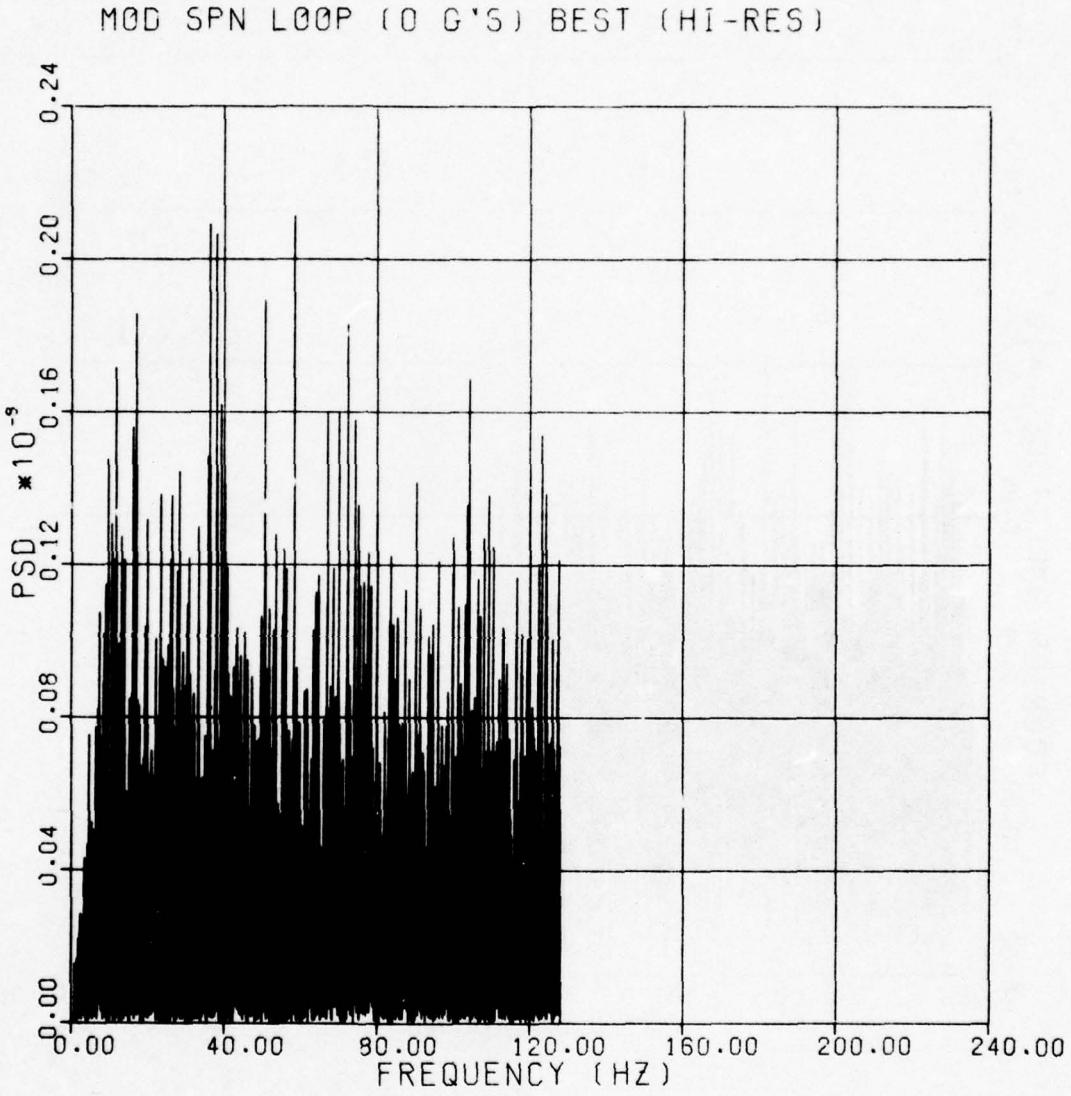


FIGURE 4.1-33. SPECTRAL DENSITY ANALYSIS RESULTS

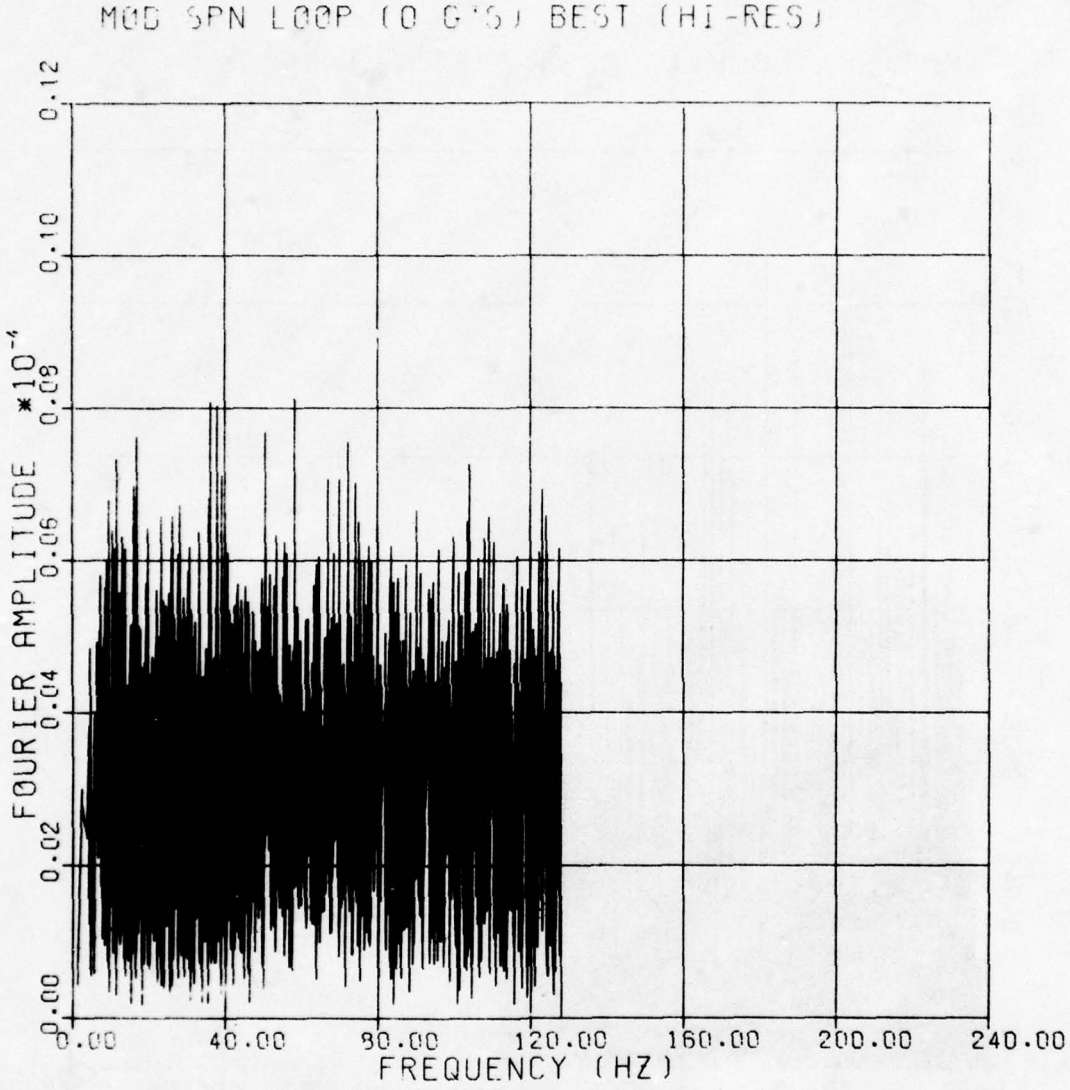


FIGURE 4.1-34. SPECTRAL DENSITY ANALYSIS RESULTS

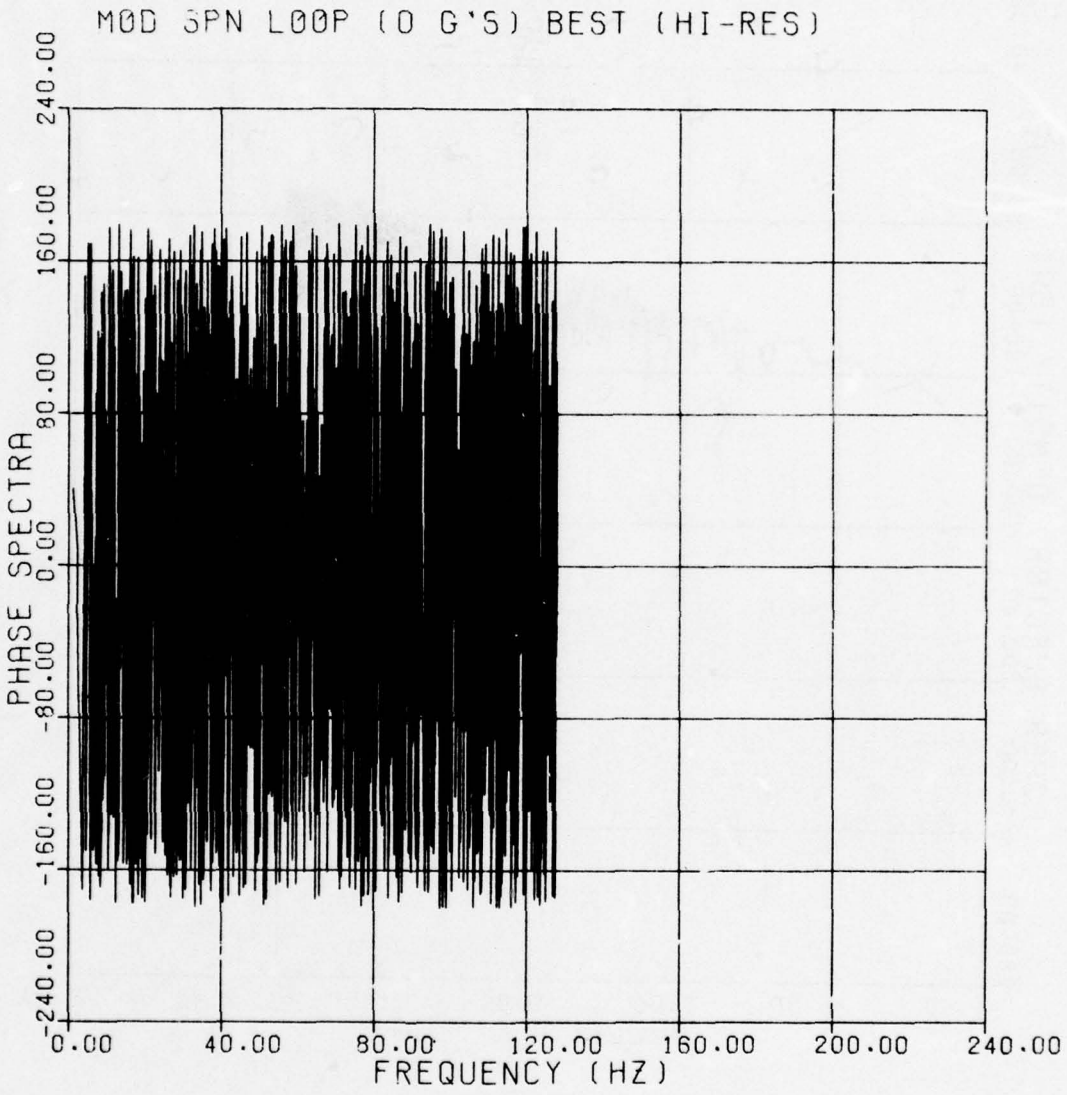


FIGURE 4.1-35. SPECTRAL DENSITY ANALYSIS RESULTS

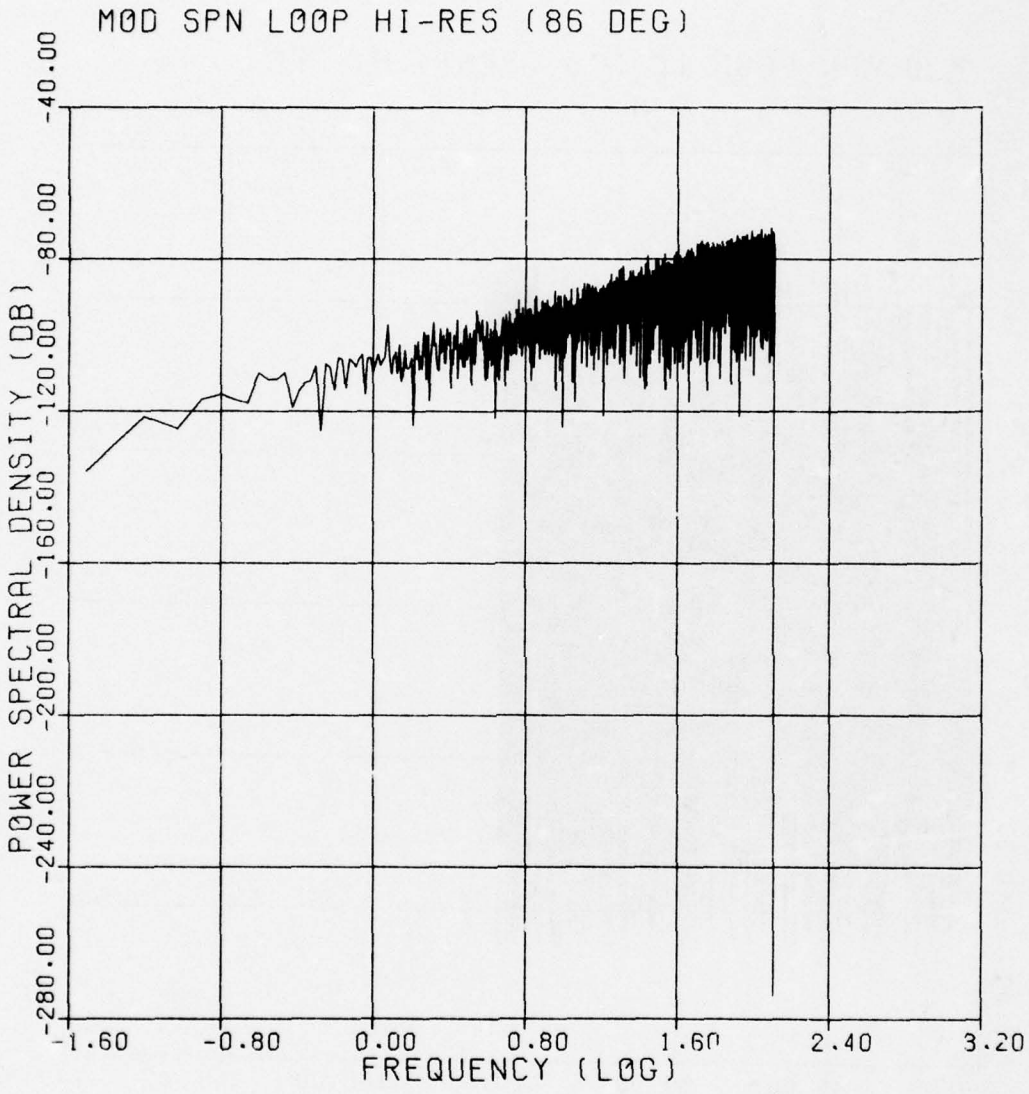


FIGURE 4.1-36. SPECTRAL DENSITY ANALYSIS RESULTS

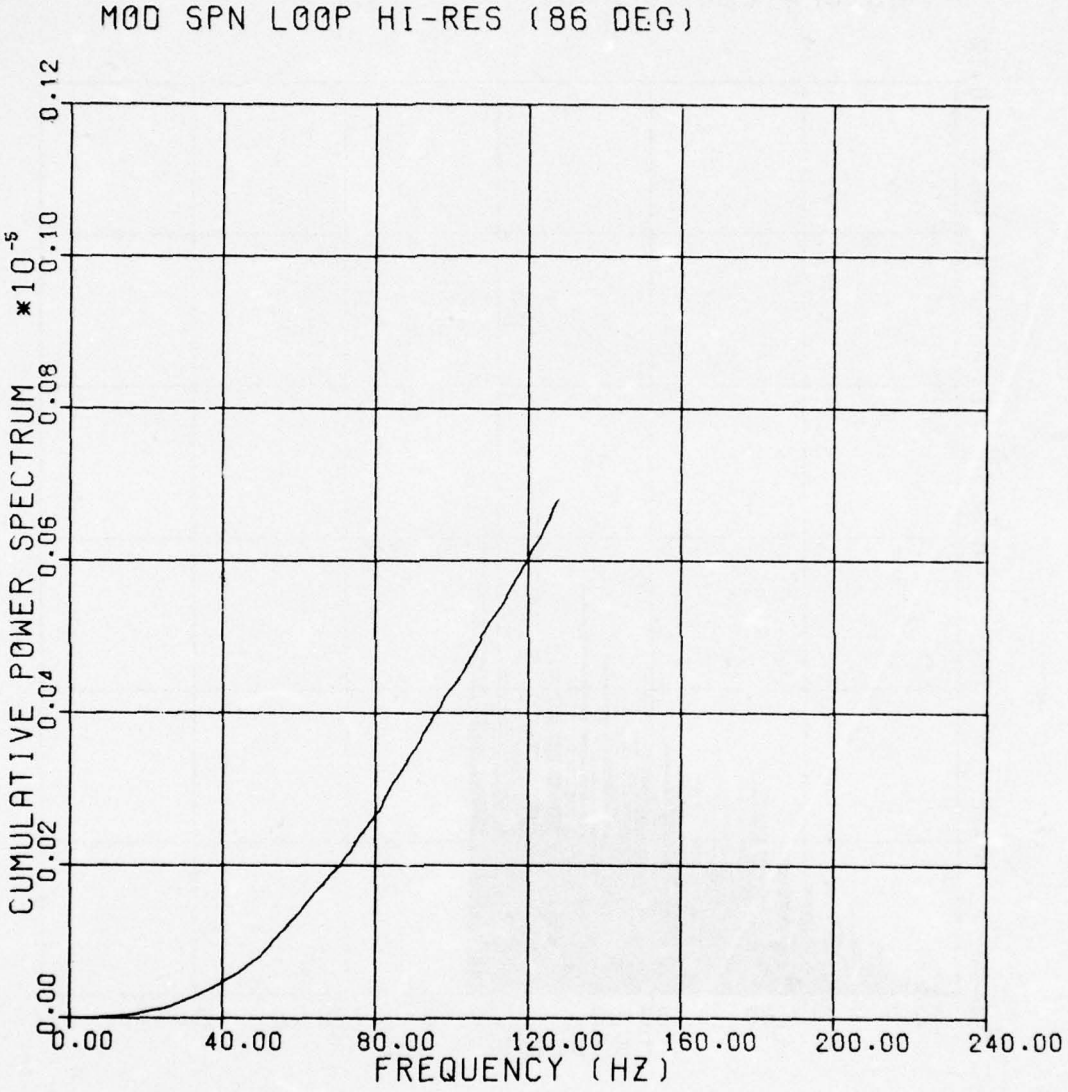


FIGURE 4.1-37. SPECTRAL DENSITY ANALYSIS RESULTS

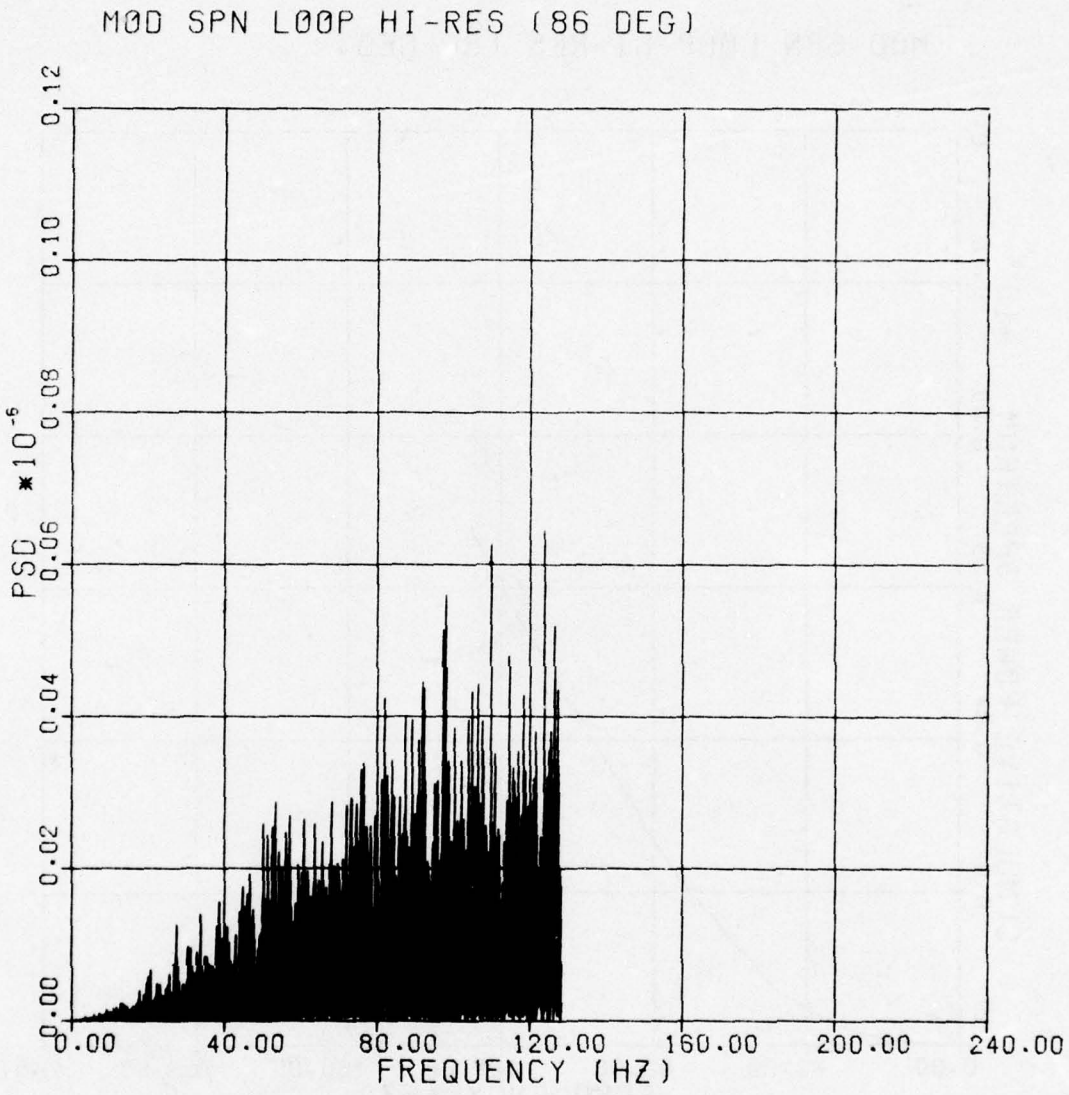


FIGURE 4.1-38. SPECTRAL DENSITY ANALYSIS RESULTS

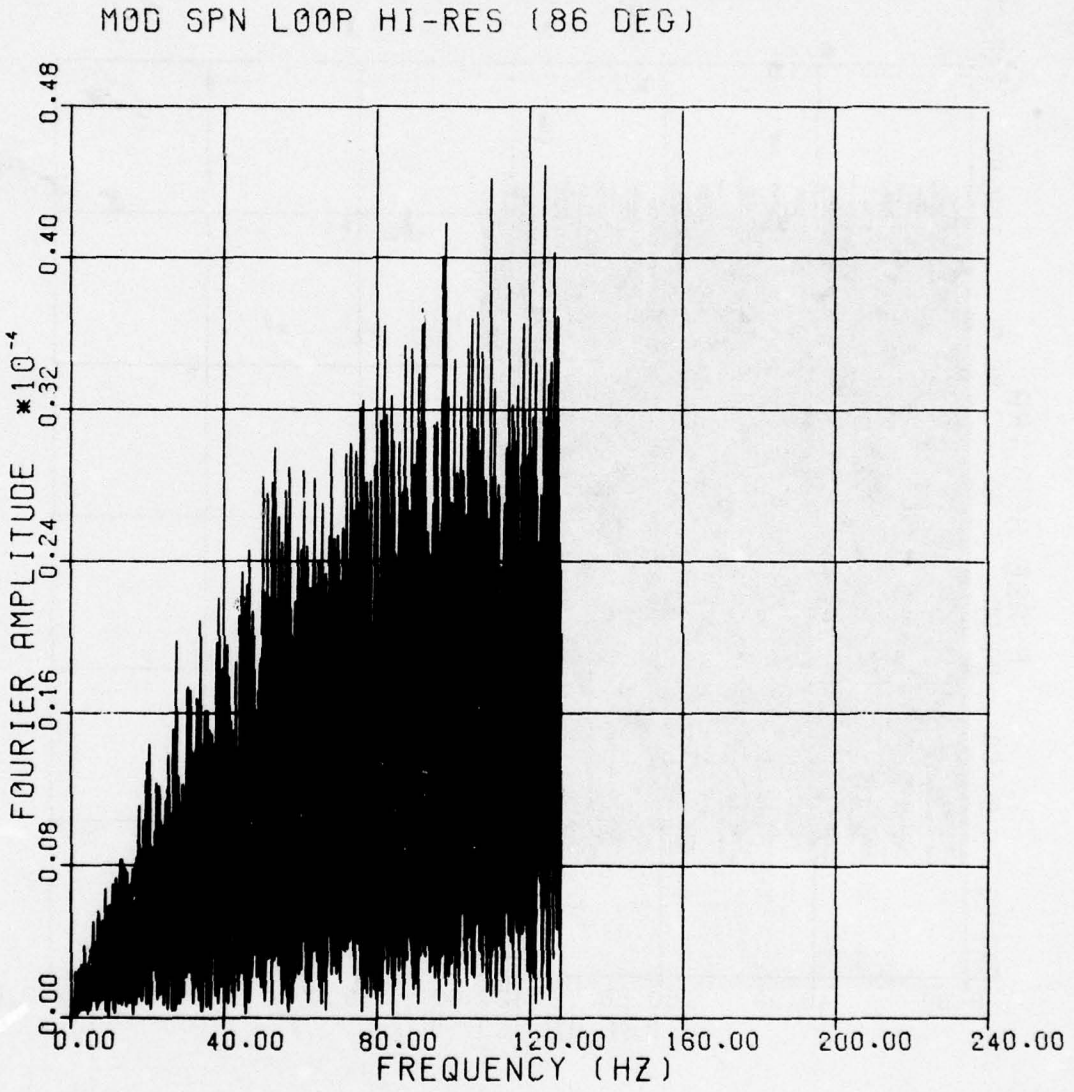


FIGURE 4.1-39. SPECTRAL DENSITY ANALYSIS RESULTS

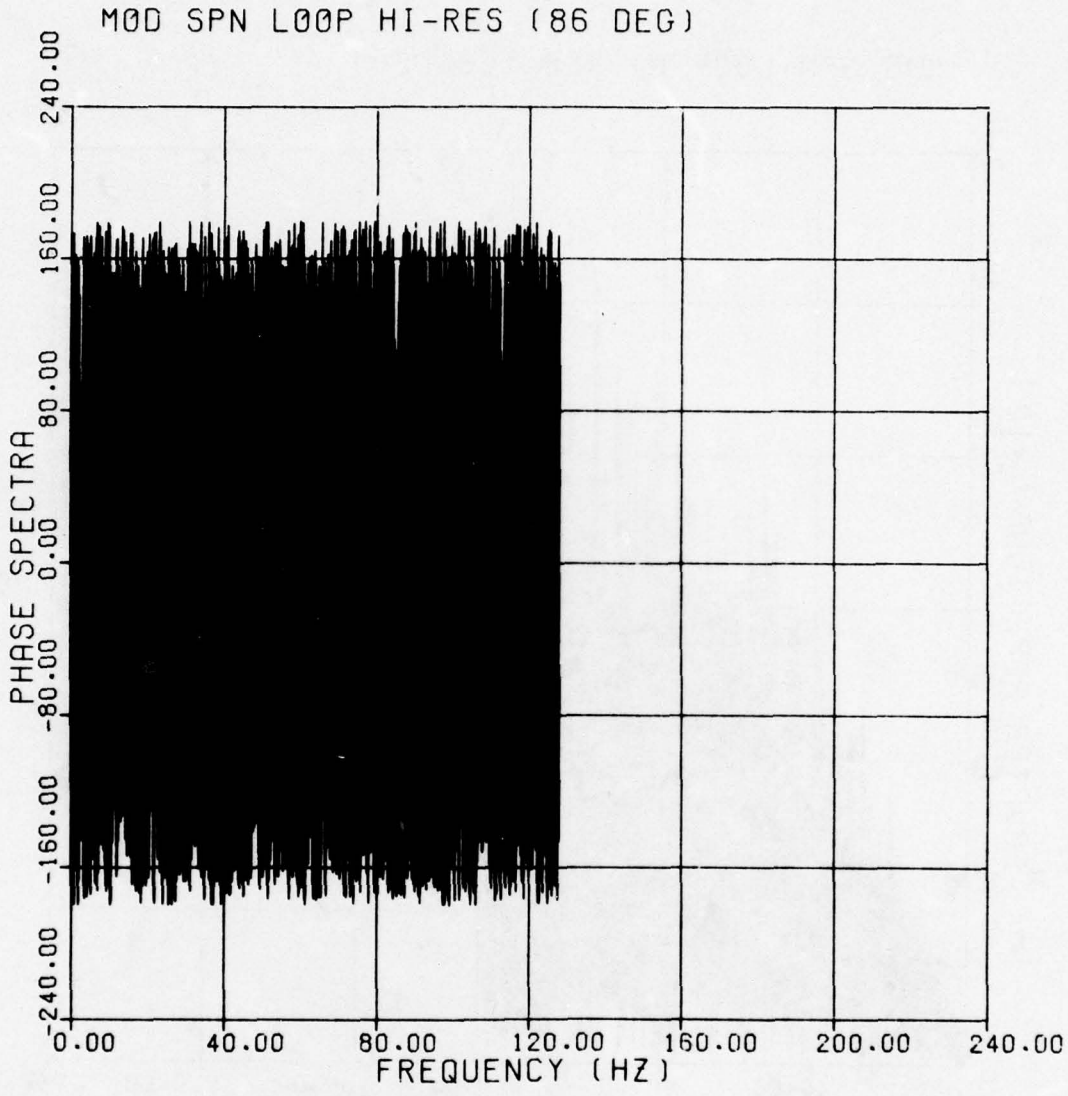


FIGURE 4.1-40. SPECTRAL DENSITY ANALYSIS RESULTS

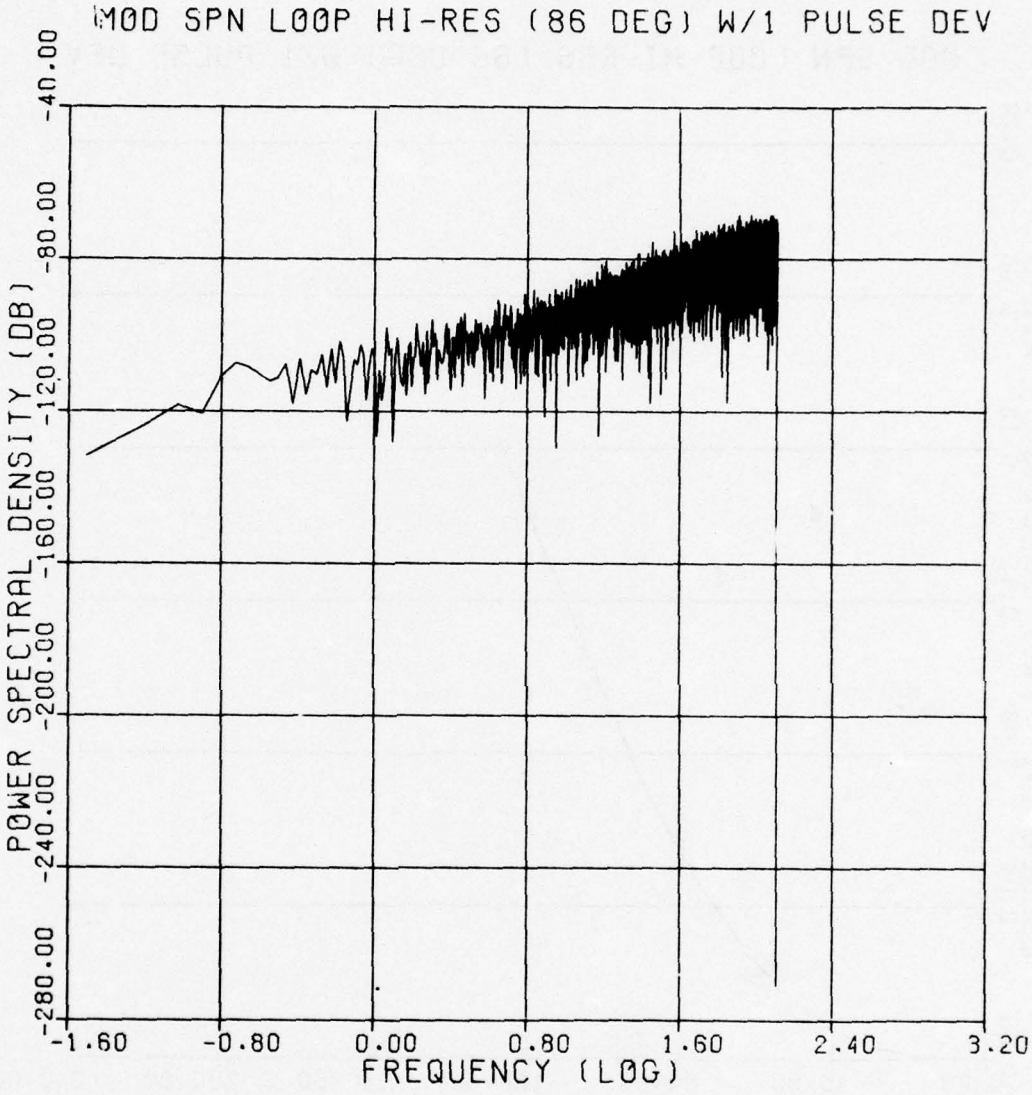


FIGURE 4.1-41. SPECTRAL DENSITY ANALYSIS RESULTS

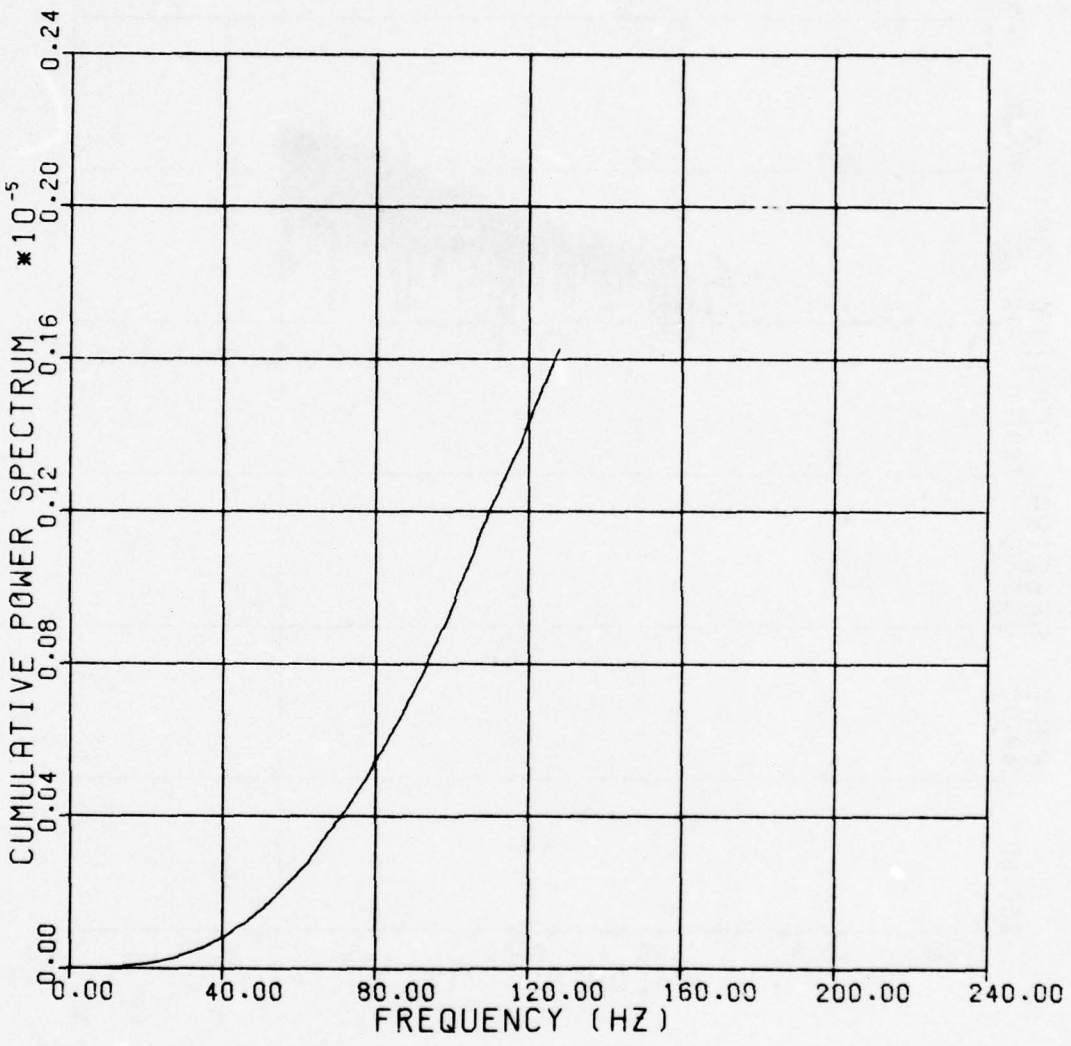


FIGURE 4.1-42. SPECTRAL DENSITY ANALYSIS RESULTS

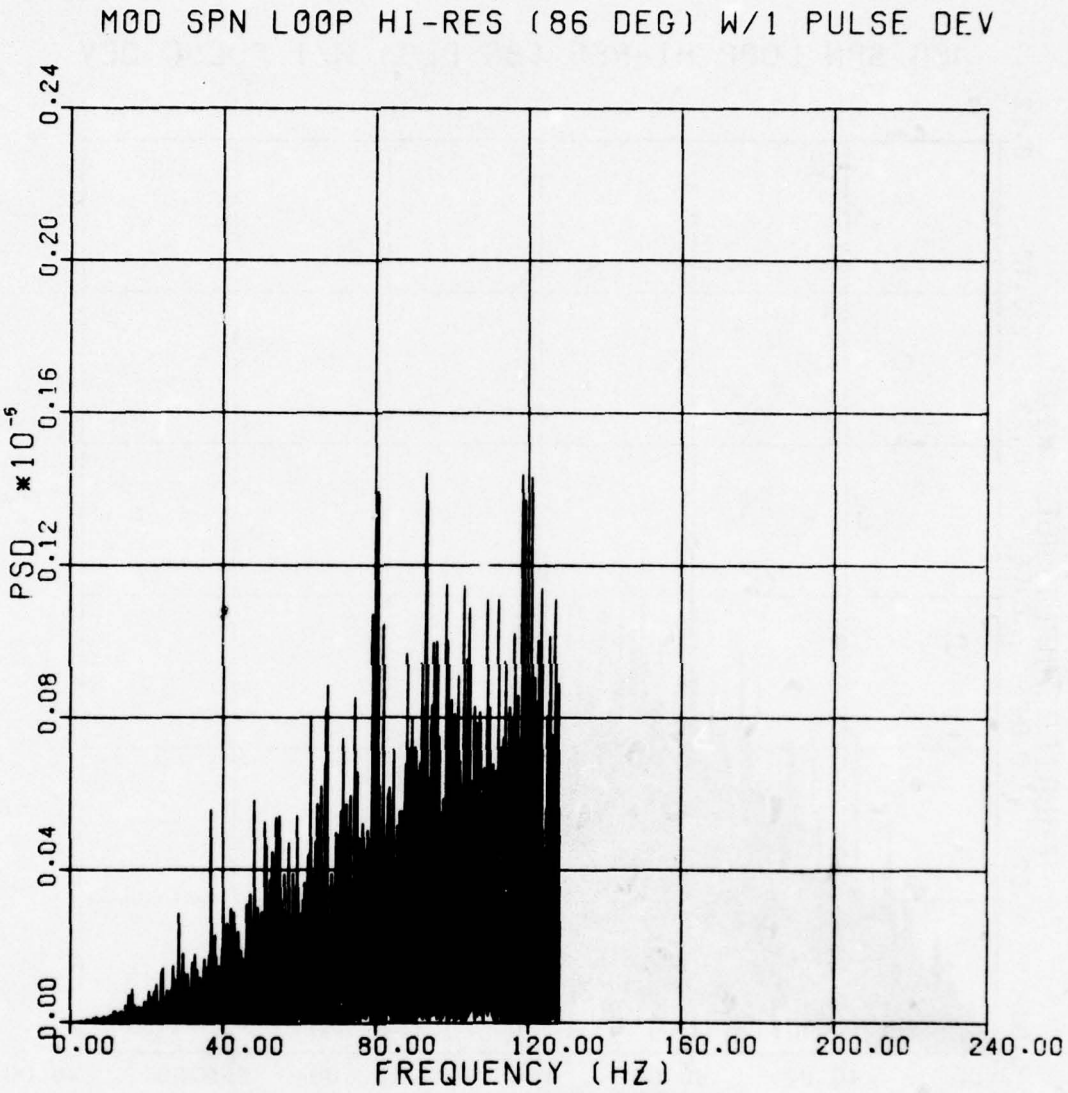


FIGURE 4.1-43. SPECTRAL DENSITY ANALYSIS RESULTS

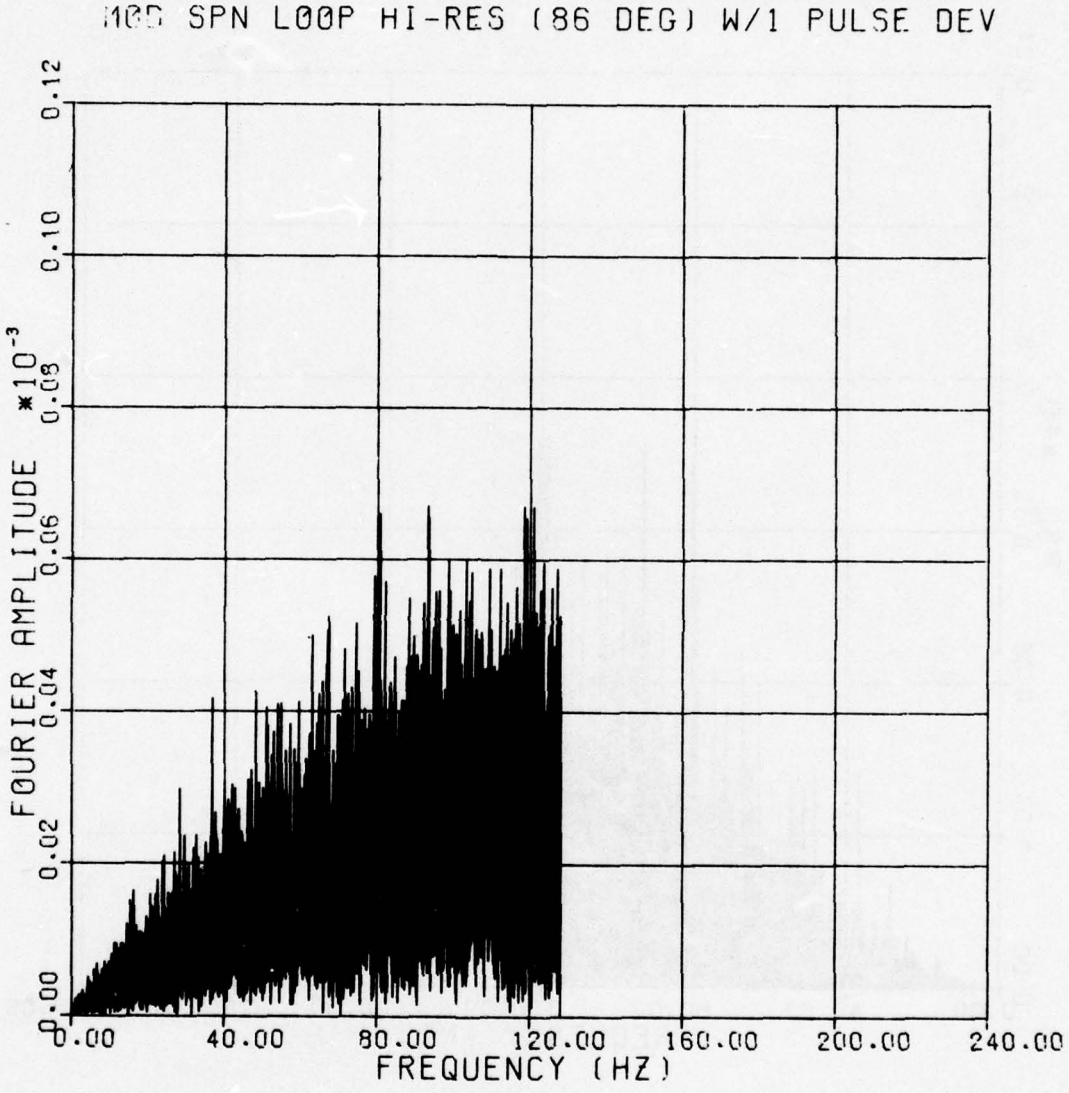


FIGURE 4.1-44. SPECTRAL DENSITY ANALYSIS RESULTS

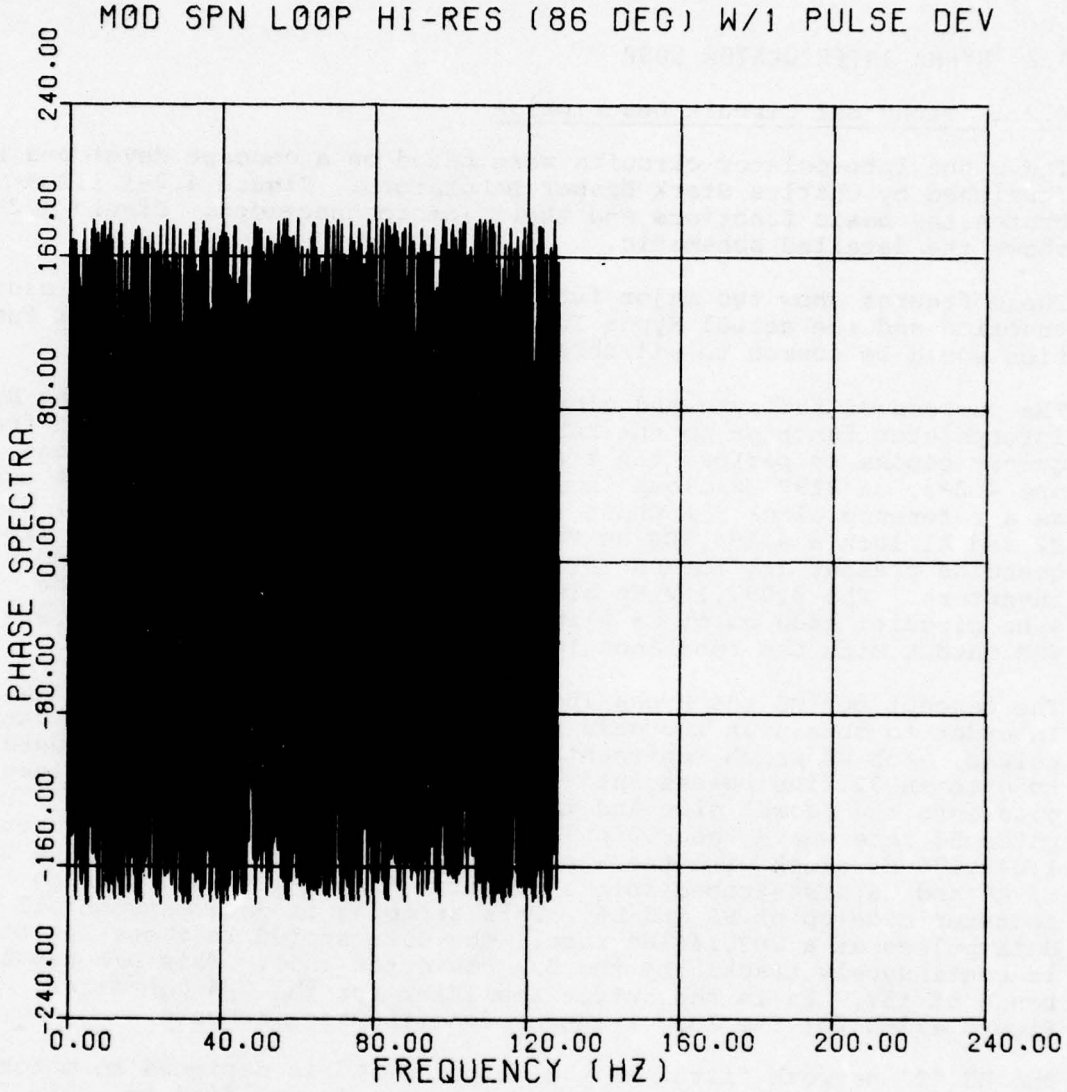


FIGURE 4.1-45. SPECTRAL DENSITY ANALYSIS RESULTS

4.2 HYPHA INTERPOLATOR LOOP

4.2.1 Technical Circuit Description

The Hypha Interpolator circuits were based on a concept developed and furnished by Charles Stark Draper Laboratory. Figure 4.2-1 illustrates the basic functions and their interconnections. Figure 4.2-2 shows the detailed schematic.

These figures show two major functions: a synchronization and clock function and the actual Hypha Interpolator. The sync and clock function would be common to all three loops in a SPN/GEANS.

The purpose of the sync and clock function is to synchronize the Hypha Interpolator function to the rebalance loop and to provide high frequency clocks to perform the required clocking. As shown in Figure 4.2-2, an 8192 Hz clock from the system timing reference is used as a reference clock. A phase lock loop made up of B1, C1, D1, E1, E2 and A1 lock a 4,194,304 Hz VCO to the 8192 clock. The high frequencies present are formed into clock pulses by "and" gates and inverters. The 2,097,152 Hz clock from C2-6 and D2-6 strobe the sync circuit, made up of C4 flip/flop which synchronizes the Hypha VCO output with the rebalance loop timing.

The concept behind the Hypha Interpolator operation is as follows. In order to obtain an increase in data resolution, the present data pulses, each of which represents 0.04 ft/sec of velocity, are used to gate in 32 fine pulses into the up/down counters. The + pulses gate into the "down" side and the - pulses into the "up" side. "OR" gates B3 interweave the VCO pulses with the $+\Delta V$ pulses and a reference 1,048,576 Hz clock with the - pulses. The up/down counter, made up of A6 and C6, is strobed into a parallel-in/parallel-out storage register made up of B6 and D6. This strobing is done between all data pulses at a 262,144 Hz rate. The data stored in these registers is continuously tracked by the D/A converter (E6). This D/A has a range of ±5V. E5 is the output amplifier for the D/A converter. See Figure 4.2-3 for the loop transfer function requirements.

The RC "T" network filter on the output of C5 is designed to match the frequency response of the pendulum signal amplifier A5. Pin 2 of B5 is the summing point at which the coarse data from the ΔV pulses and the complete data from the pendulum are combined to achieve the increase in resolution.

B5 is a loop compensation amplifier used to set loop gain and to drive the VCO. A bias network is used on the VCO (B4) to set its center operating frequency (1,048,576 Vz). The output of the VCO goes into the sync circuit (C4) and thus completes the loop.

The pendulum signal amplifier A5 was designed to perform several functions:

1. Amplify the pendulum signal.

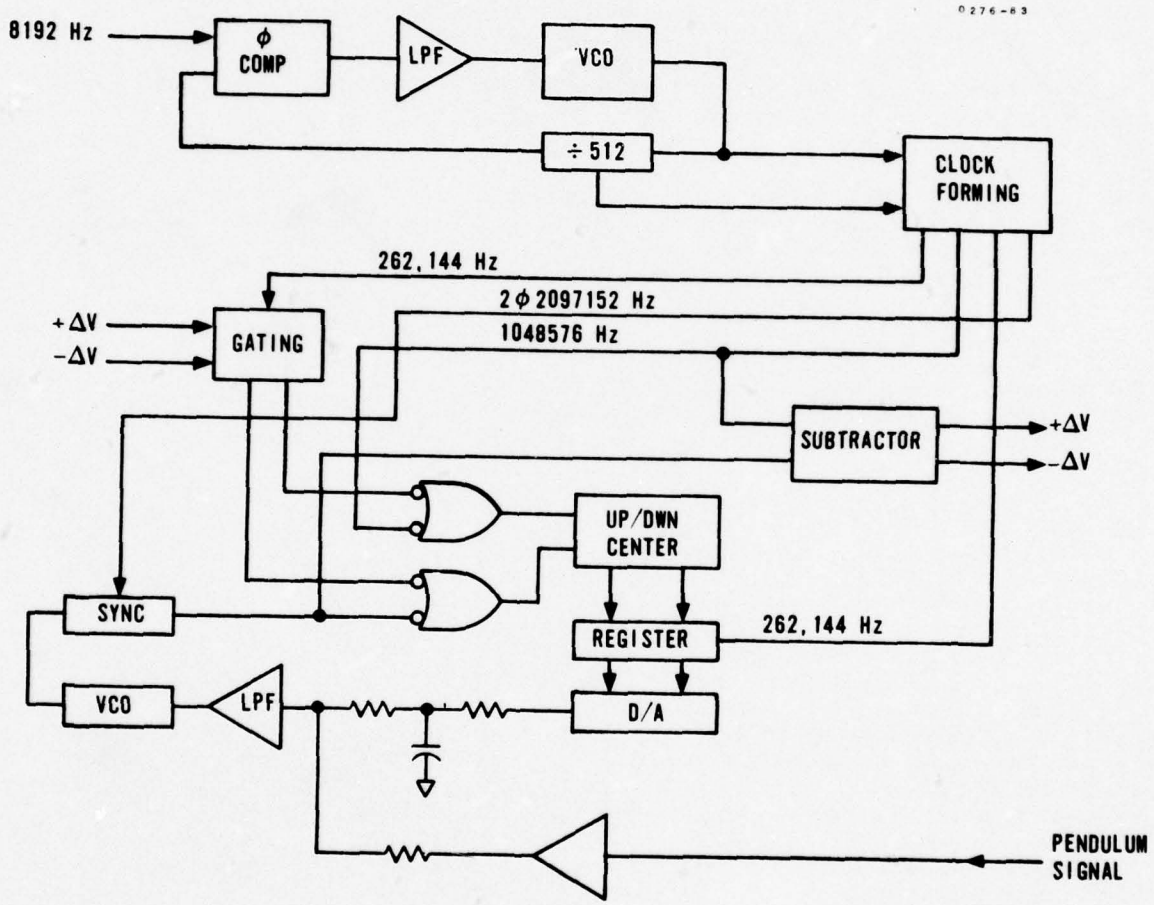
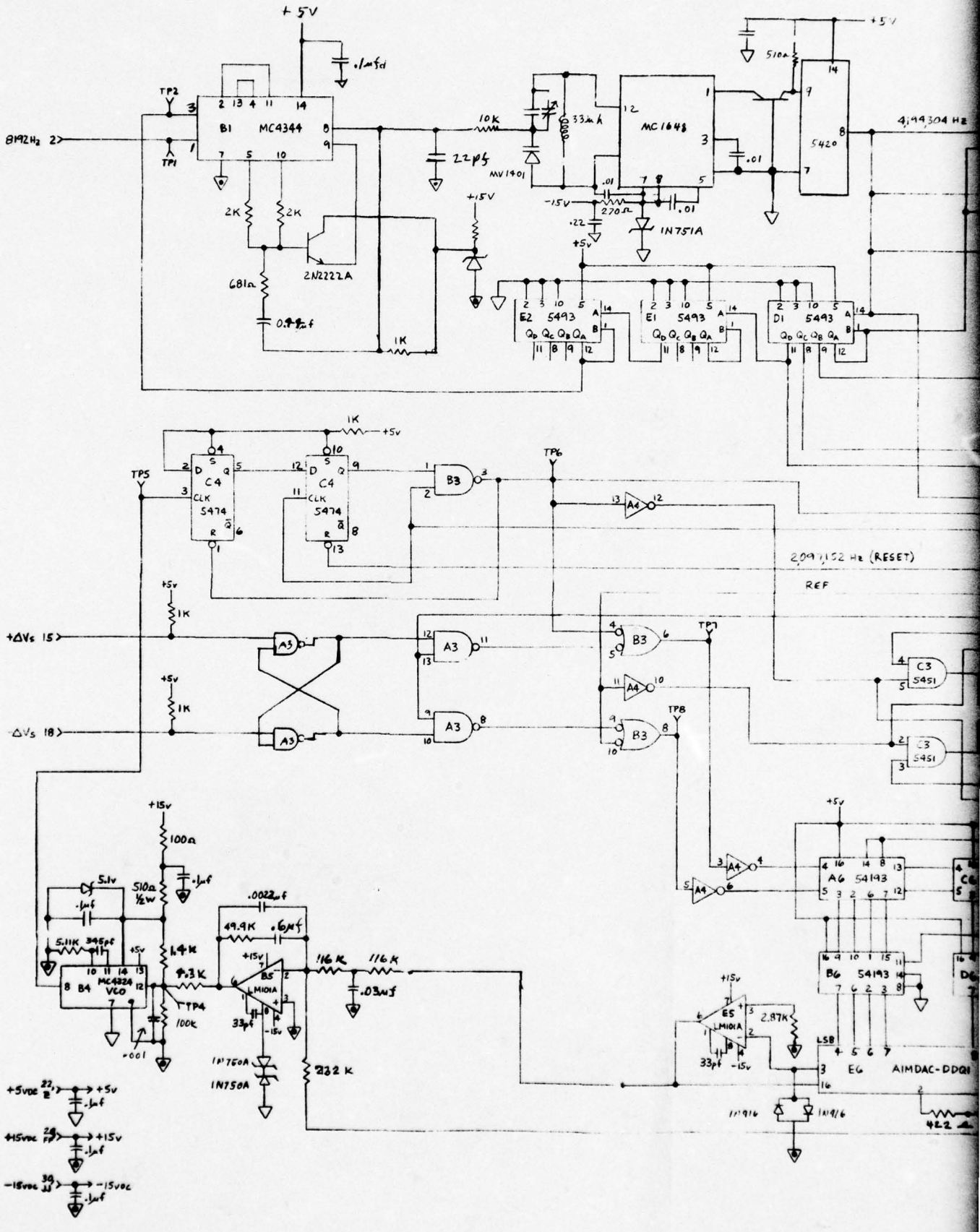


FIGURE 4.2-1. BLOCK DIAGRAM HYPHA INTERPOLATOR


+5V
.1mfd
TP2
TP1
8192H2
B1 MC4344
10K
22pf
MV1401
33mh
MC1648
5420
4,194,304 HZ
510Ω
.01
270Ω
.22
1N751A
-15V
+15V
2K
2K
2N2222A
681Ω
.01mf
1K
E2 5493
E1 5493
D1 5493
C4 5474
TP5
TP6
B3
A4
2,097,152 Hz (RESET)
REF
+ΔVs 15
ΔVs 18
A3
TP7
TP8
C3 5451
100Ω
5.1v
510Ω ½w
.1mf
.0022mf
49.9K
.6mf
5.11K
345pf
1.4K
9.3K
MC4324 VCO
B4
TP4
100K
.001
116K
116K
.03mf
B5 M101A
33pf
1N750A
232K
A6 54193
B6 54193
E5 M101A
2.87K
LSB
E6
AIMDAC-DDQI
1N916
422
+5VDC
+15VDC
-15VDC
.1mf

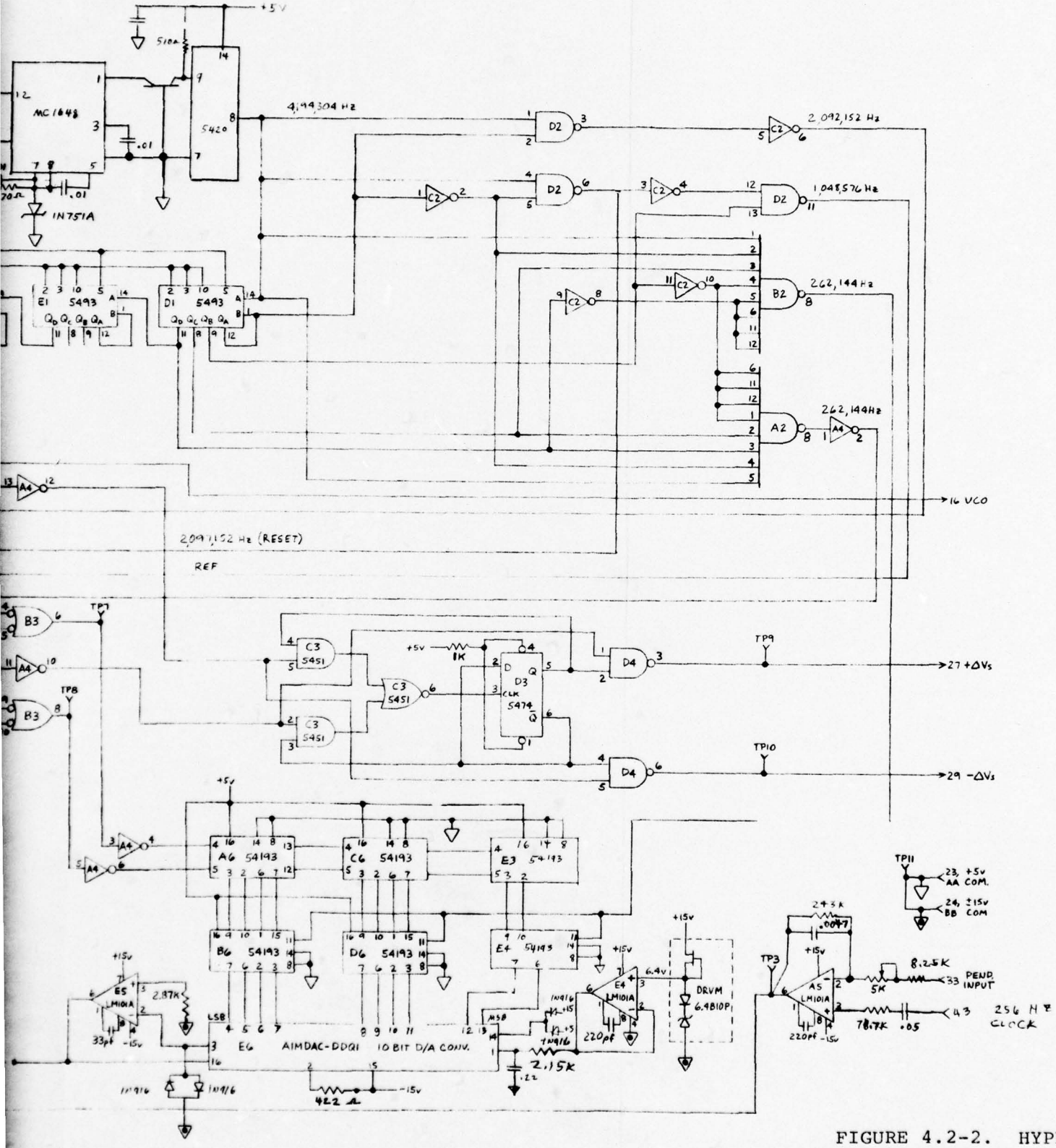


FIGURE 4.2-2. HYPHA INTERPOLATOR

2

2. Filter out the demodulator noise.

3. Provide dc offset correction.

The potentiometers shown would be replaced by fixed resistors in a final system configuration.

The output data is obtained by subtracting the VCO signal from the 1,048,576 Hz reference clock. The output of the subtractor is a pulse train whose frequency is the difference between the two inputs. If the VCO frequency is greater than the reference, the pulses are seen at D4-3; if less than the reference, the pulses at D4-6. Each pulse output has a weight of 1/32 of each coarse pulse.

The circuitry shown here was constructed on a single circuit board, designed to be plugged into the SPN/GEANS brassboard.

4.2.2 Status of Effort

All the tests planned have been performed on the Hypha Interpolator except the simulated higher g tests. As stated in the HRPWM section, this test proved to be unrealiable in judging high resolution techniques.

4.2.3 Brassboard Test Results

4.2.3.1 Bench Test

The tests performed on the Hypha Interpolator were in two steps.

First, the circuit was connected to power sources on the bench and simulated ΔV pulses used to excite it. In this case, the crystal VCO was connected around itself and served as the reference. The waveforms for each ΔV pattern are shown in Figures 4.2-3 through 4.2-10. A counter was used to verify that the proper nominal count was obtained for each simulated g input as follows:

0 g's 0 Count

±2.5 g's - ±65.5 kHz

±5 g's - ±131.0 kHz

±10 g's - ±262.1 kHz

Another test performed was a loop response test. A pulse train was inserted into the pendulum amplifier and oscilloscope photographs taken of the waveforms at points A & B as shown in Figures 4.2-11 through 4.2-13.

Following the loop transient response tests, a loop frequency response test was performed by substituting a sine wave oscillator for the pulse generator. The frequency was swept from 100 Hz to 4000 Hz. The data plot is shown in Figure 4.2-13.

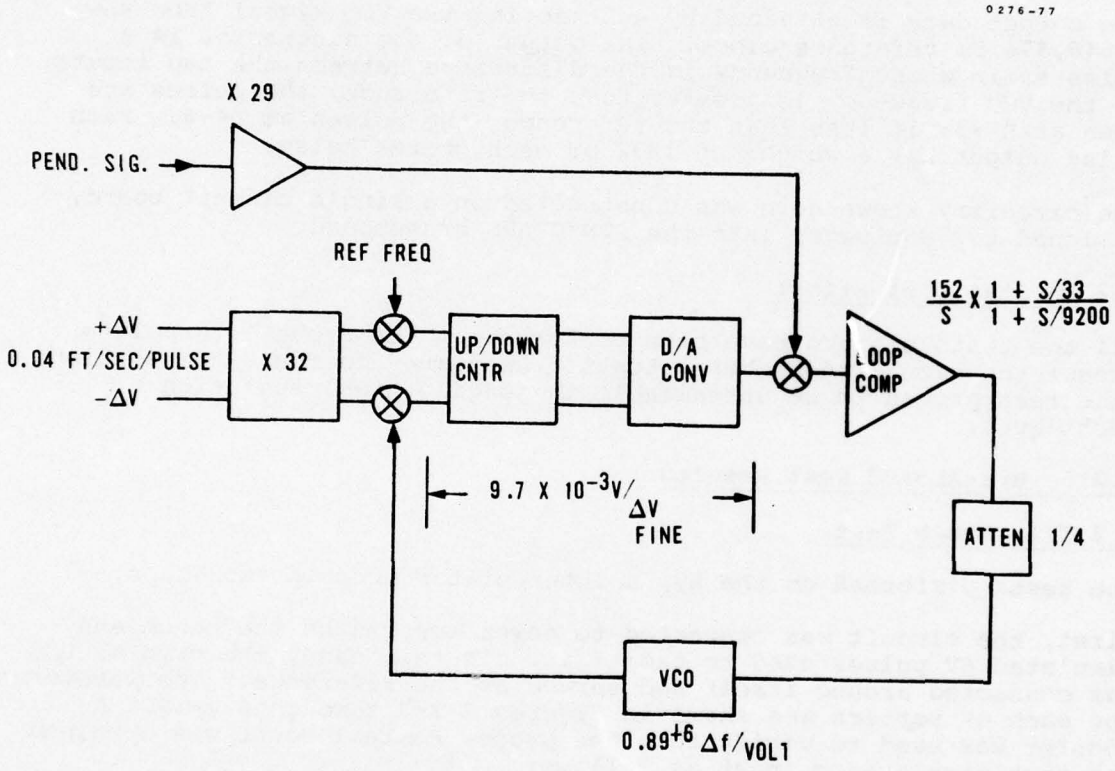


FIGURE 4.2-3. HYPHA LOOP TRANSFER FUNCTIONS

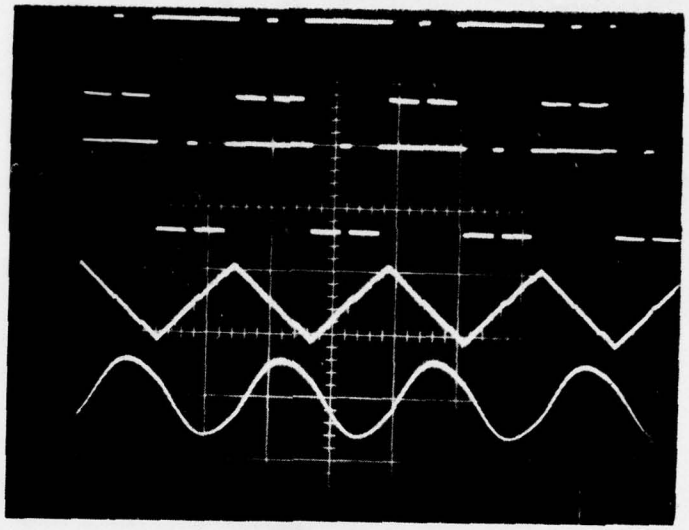
CHAN.

1

2

3

4



CHAN.

1 -ΔV INPUT 2V/CM
2 +ΔV INPUT 2V/CM
3 D/A OUTPUT 1V/CM
4 OUTPUT OF B5 1V/CM

FIGURE 4.2-4. SIMULATED 0g WAVEFORMS

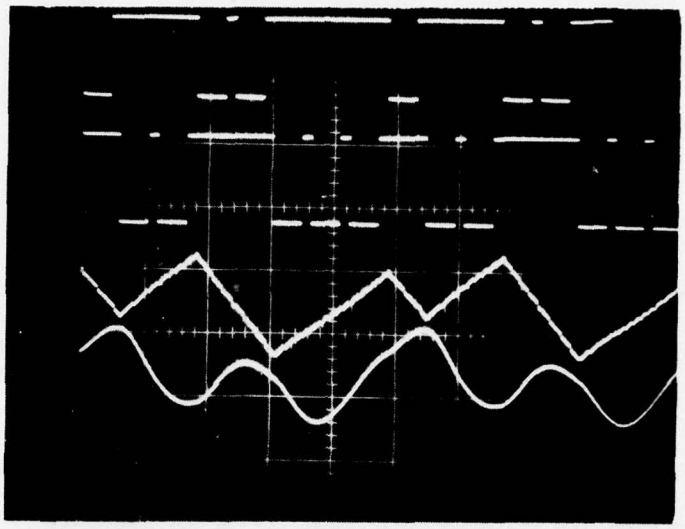


FIGURE 4.2-5. SIMULATED +2.5 g's

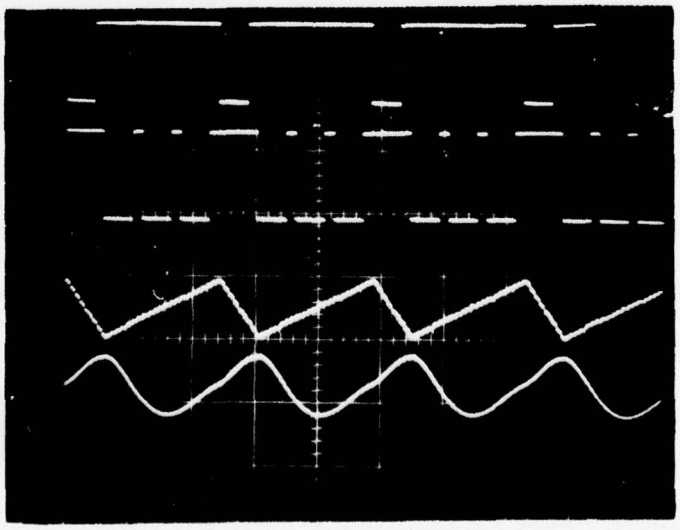


FIGURE 4.2-6. SIMULATED +5 g's

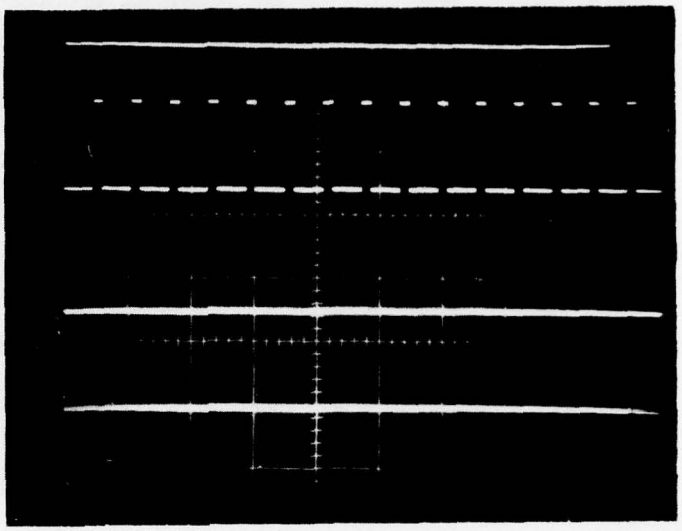


FIGURE 4.2-7. SIMULATED +10 g's

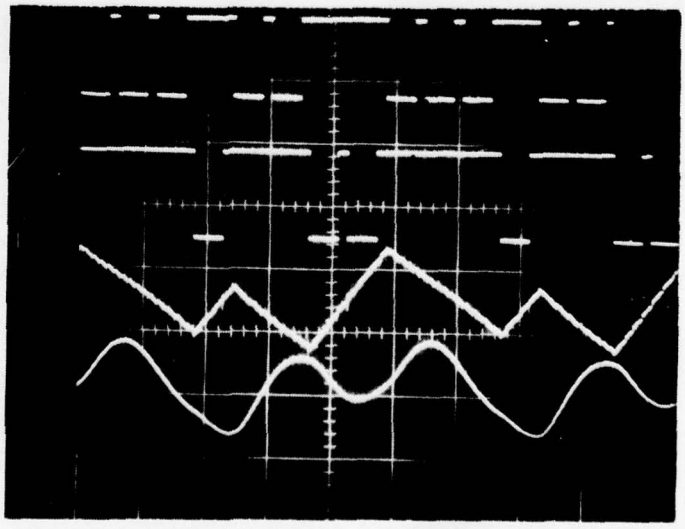


FIGURE 4.2-8. SIMULATED -2.5 g's

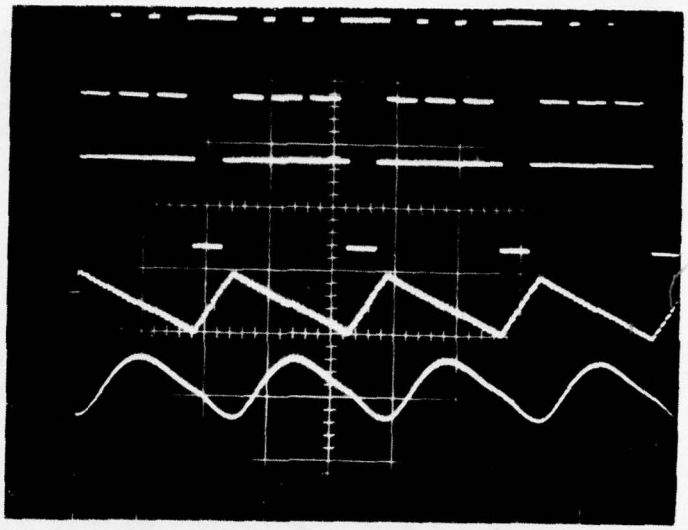


FIGURE 4.2-9. SIMULATED -5 g's

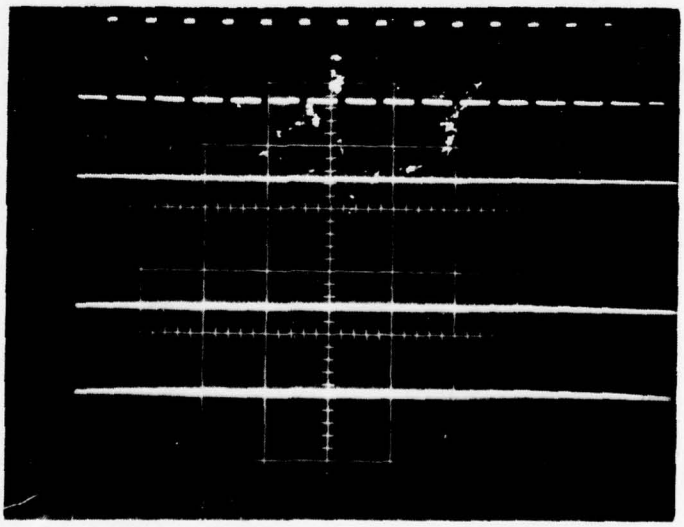


FIGURE 4.2-10. SIMULATED -10 g's

0276-80

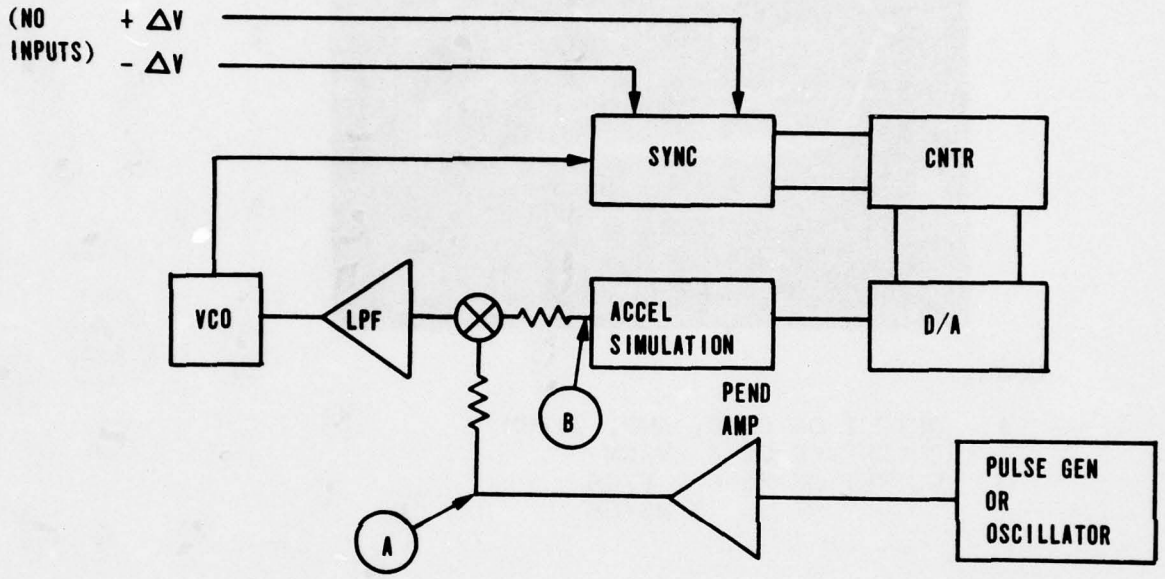
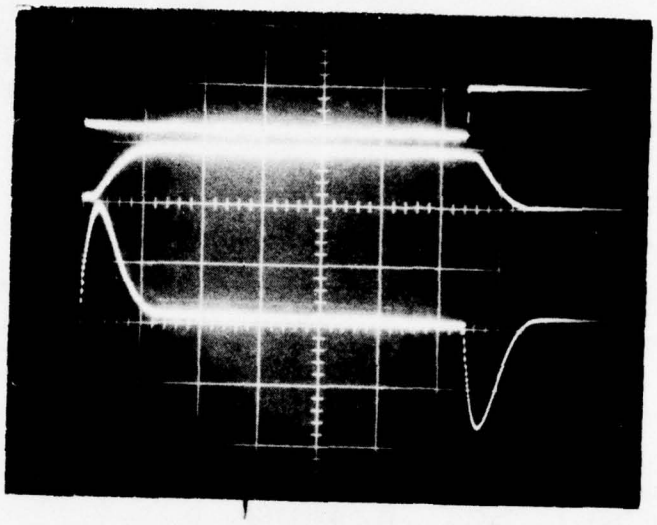


FIGURE 4.2-11. TEST CONNECTIONS FOR LOOP RESPONSE

CHAN.



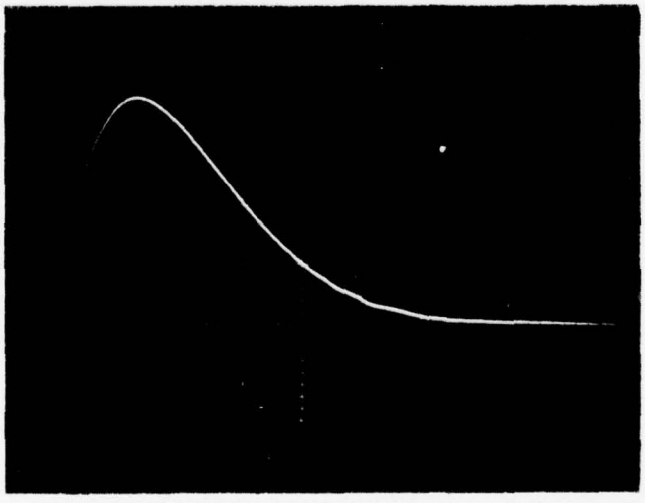
1

2

3

CHAN.

1 OUTPUT OF PEND. AMP. 2V/CM
2 OUTPUT OF C5-6 2V/CM
3 OUTPUT OF B5-6 1 V/CM
1 MS/CM



0.2 MS/CM
0.5V/CM

FIGURE 4.2-12. EXPANDED VIEW OF B5-6 OUTPUT

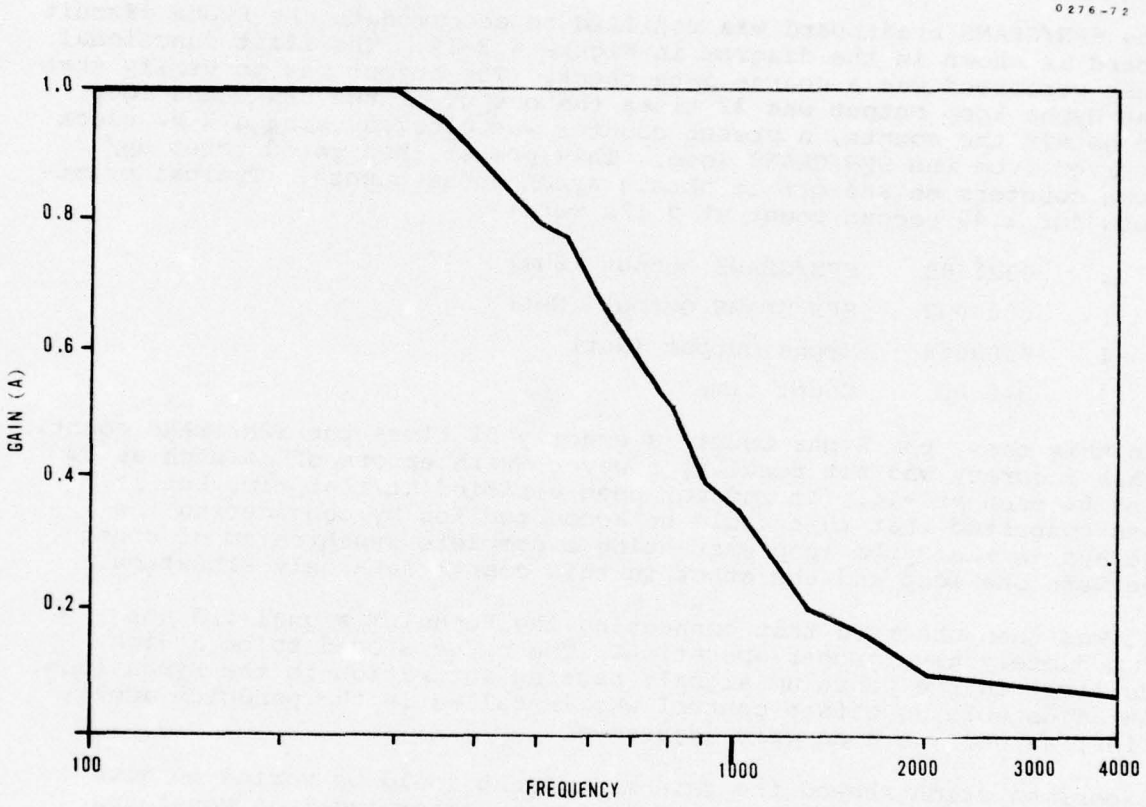


FIGURE 4.2-13. PLOT OF LOOP OUTPUT VOLTAGE VERSUS INPUT FREQUENCY

4.2.3.2 Brassboard Test Results

The SPN/GEANS brassboard was modified to accommodate the Hypha circuit board as shown in the diagram in Figure 4.2-14. The first functional test performed was a coarse data check. The object was to verify that the Hypha loop output was 32 times the output of the SPN/GEANS loop. To obtain the counts, a preset counter was clocked using a 2 Hz clock derived from the SPN/GEANS loop. This preset then gated three up/down counters on and off to obtain synchronous counts. Typical printouts for a 40 second count at 0 g's were:

2	0327680	SPN/GEANS Output (Sum)
1	0000002	SPN/GEANS Output (Net)
4	0000064	Hypha Output (Net)
3	040.00	Count Time

In this case, the Hypha Count is exactly 32 times the SPN/GEANS count. This accuracy was not regular, however, with errors of as much as 32 and 64 seen at +1g. It had not been verified at that time but it was suspected that this could be accounted for by considering the delays in the Hypha loop preventing a complete synchronism of count between one loop and the other in this coarse data only situation.

It was then observed that connecting the Pendulum signal did not immediately give proper operation. The cause proved to be a high dc level in the pendulum signal, causing saturation in the Hypha loop. An adjustable dc offset control was installed in the pendulum amplifier, as well as a dc gain adjustment.

Experimentation showed the gain adjustment could be varied to give the best possible smoothness of counts by observing loop waveforms for proper cancellation.

Once functional operation was obtained, 2 four-point Linearity tests were performed. The data is shown below:

Run No. 1

Angle	SPN Count	Hypha Count
0 deg	+32394	1036653
90 deg	-12	-375
180 deg	-32384	-1036299
270 deg	+32392	+998

SPN Error = 120 ppm

Hypha Error = 129 ppm

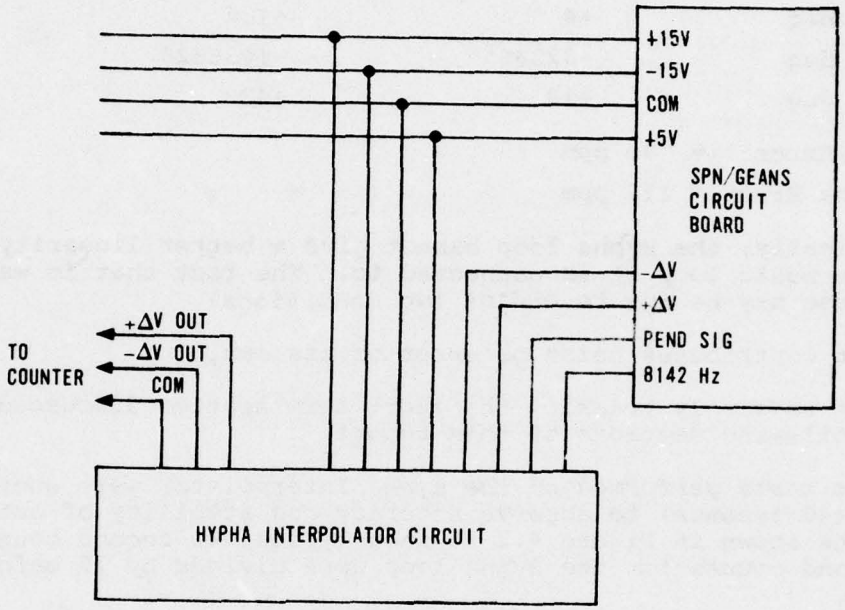


FIGURE 4.2-14. INTERCONNECTION BETWEEN BRASSBOARD AND HYPHA CIRCUIT

Run No. 2 Angle	SPN Count	Hypha Count
0 deg	+32396	+1036654
90 deg	+4	+136
180 deg	-32386	-1036320
270 deg	+12	+432

SPN Error = 90 ppm

Hypha Error = 117 ppm

Theoretically, the Hypha loop cannot give a better linearity error than the basic loop it is connected to. The fact that is was somewhat worse may be due to one of two conditions:

1. It contributes noise or error of its own,

2. It is simply tracking the short term scatter discussed in following sections of this report.

The next tests performed on the Hypha Interpolator were short term counts (40 seconds) to observe accuracy and stability of output data. The plots shown in Figure 4.2-15 show typical 40 second counts. The 800 second counts for the Hypha loop were divided by 20 before being plotted.

Following this initial run, the "T" type RC filter network was inserted after C5 and the 330 pf capacitor added to A5. These modifications were intended to force an equal attenuation of 2000 Hz in both legs of the summing point inputs. The plots in Figure 4.2-16 show various 40 second counts made with various gain adjustments and circuit configurations. The first observation from these plots is that a different pendulum amplifier gain setting is required for best performance at 0g and at +1g although this must be investigated further.

The next data taken is shown in Figure 4.2-17. Various combinations of gain settings and pendulum signal only configurations were tried. The +1g counts with the best gain adjustment show a peak-to-peak scatter of approximately 20 ppm.

This value appeared to be about the best obtainable up to that time. The photographs shown in Figure 4.2-18 through 4.2-21 show the waveforms in the loop at +1g.

Another run of 40 second counts was made with the latest circuit configuration. The results are shown in Figure 4.2-22. The scatter or spread here is approximately 40 ppm. This may have been due to an improperly set Pendulum amplifier gain.

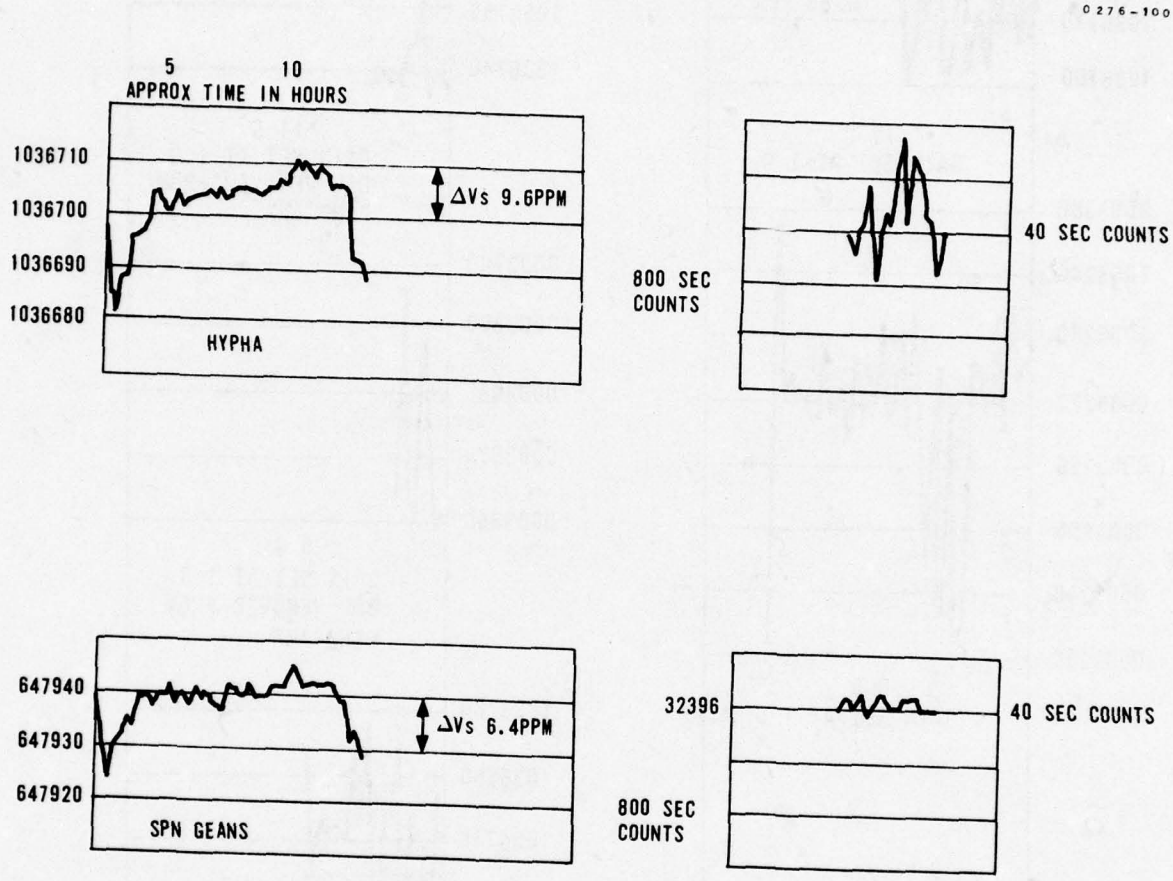


FIGURE 4.2-15. HYPHA LOOP

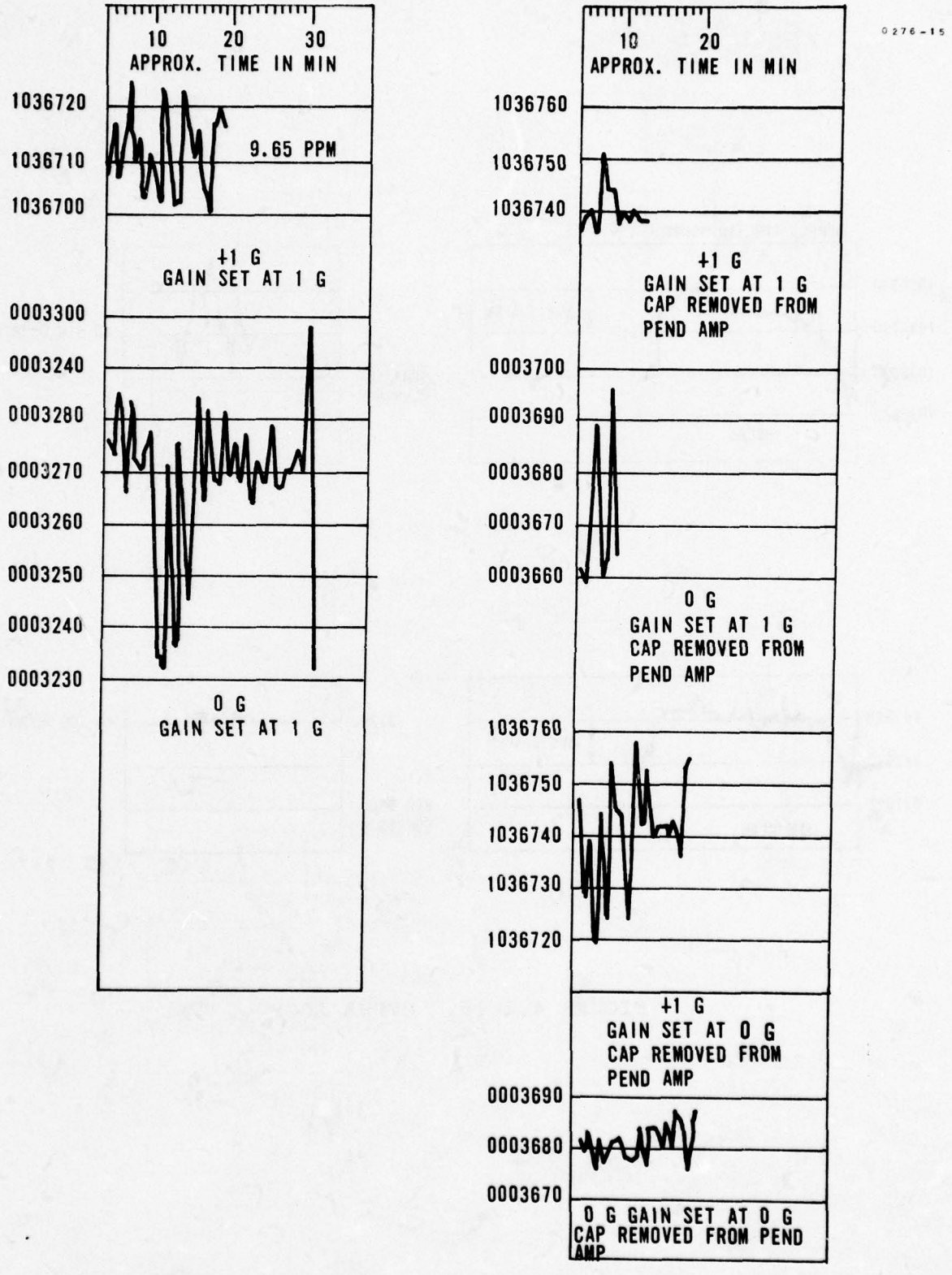


FIGURE 4.2-16. HYPHA BOARD - 40 SECOND COUNTS
10/29/74

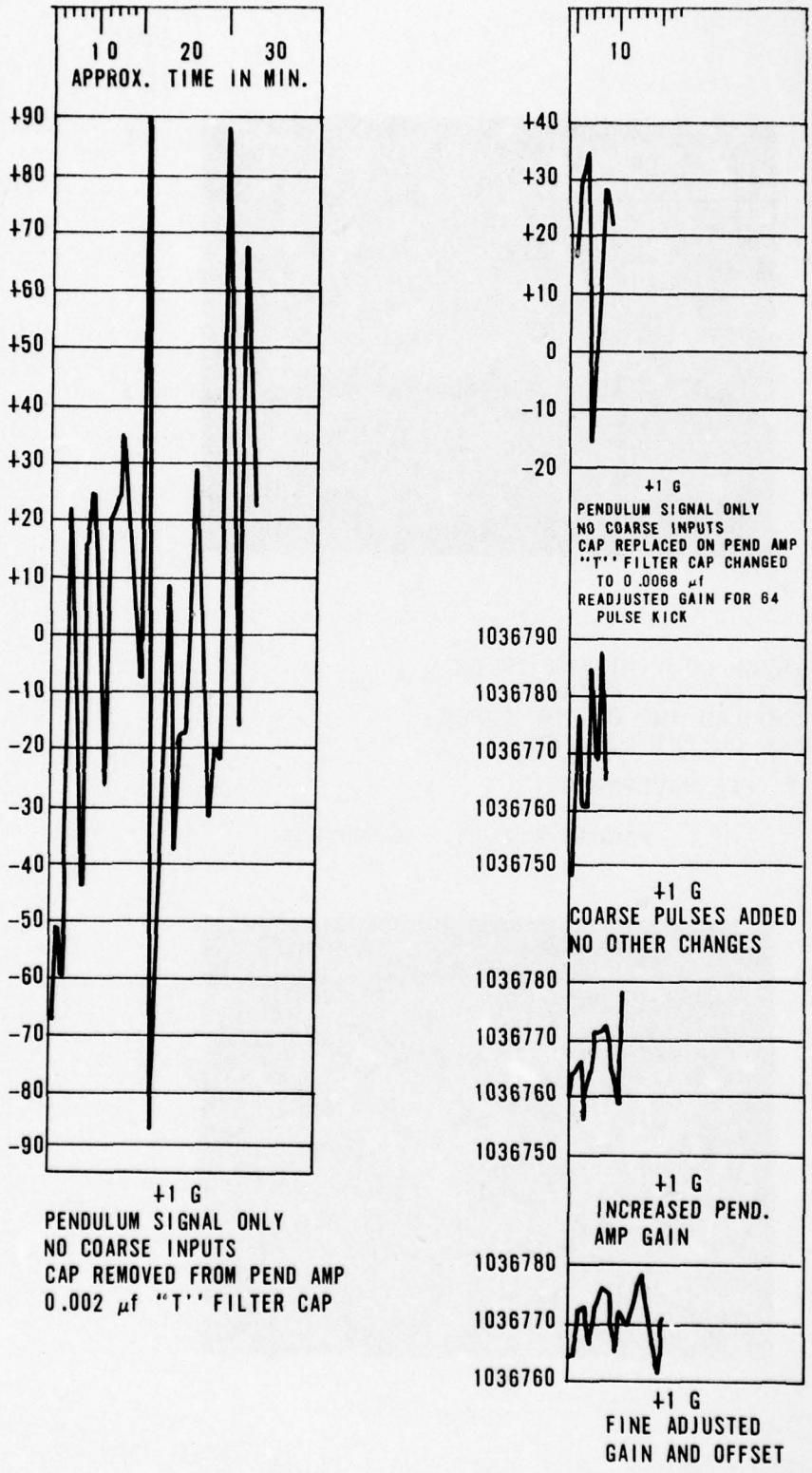
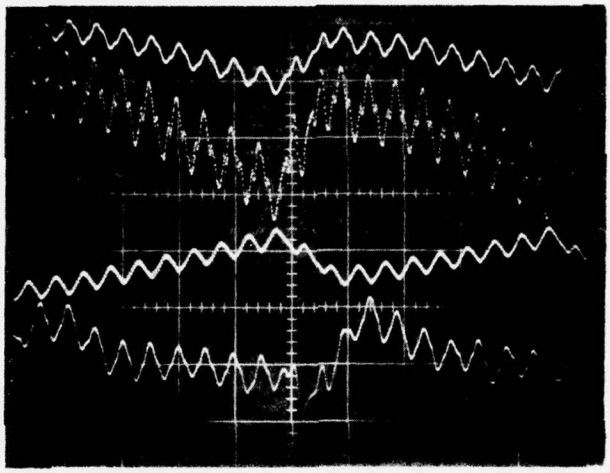


FIGURE 4.2-17. HYPHA BOARD - 40 SECOND COUNTS
10/30/74

CHAN.



1

2

3

4

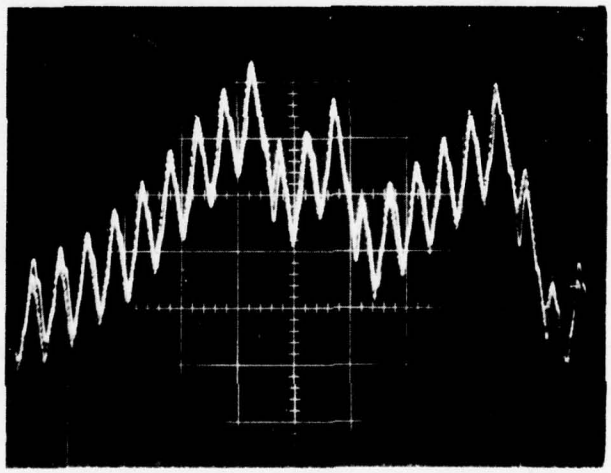
CHAN.

1 CENTER OF T-FILTER 2V/CM
2 C5-6 OUTPUT 2V/CM
3 PENDULUM AMP OUTPUT 5V/CM
4 B5-6 OUTPUT 0.5V/CM

1 MS/CM

+1g WAVEFORMS

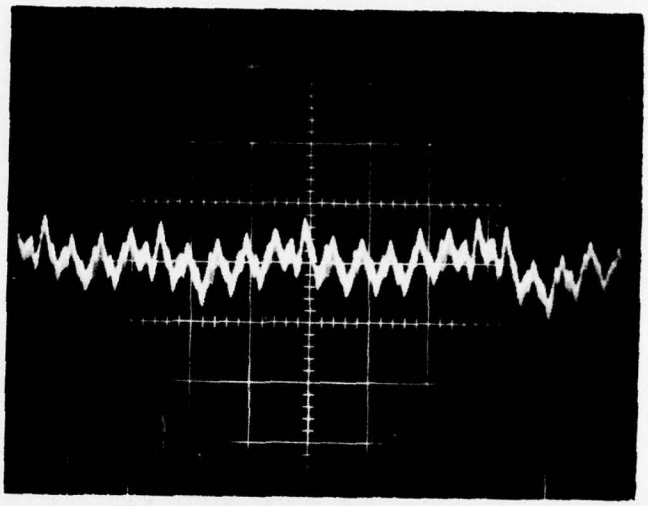
FIGURE 4.2-18. WAVEFORMS



1 MS/CM

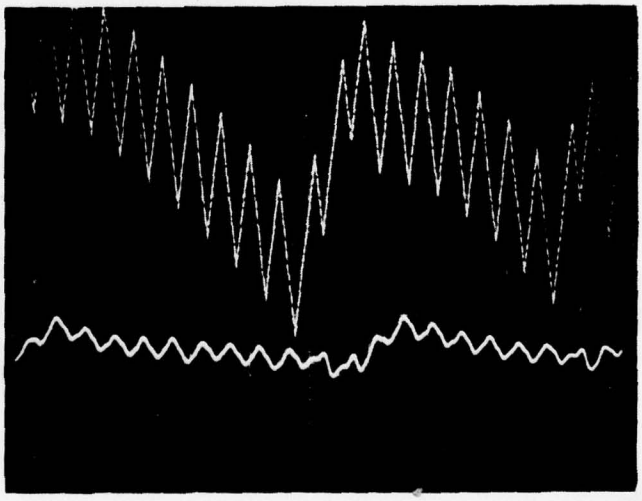
TWO SUMMING POINT WAVEFORMS SUPERIMPOSED
T-FILTER CENTER VOLTAGE INVERTED -0.5V/CM
PEND. AMP OUTPUT - 1V/CM

FIGURE 4.2-19. WAVEFORMS



SAME SIGNALS AND SCALE AS FIG. 4.2-19 EXCEPT SCOPE IS IN ADD MODE AND T-FILTER SIGNAL NOT INVERTED.

FIGURE 4.2-20. WAVEFORMS



1

2

CHAN.

1 D/A OUTPUT 1V/CM
2 B5-6 OUTPUT 1V/CM

1 MS/CM

FIGURE 4.2-21. WAVEFORMS

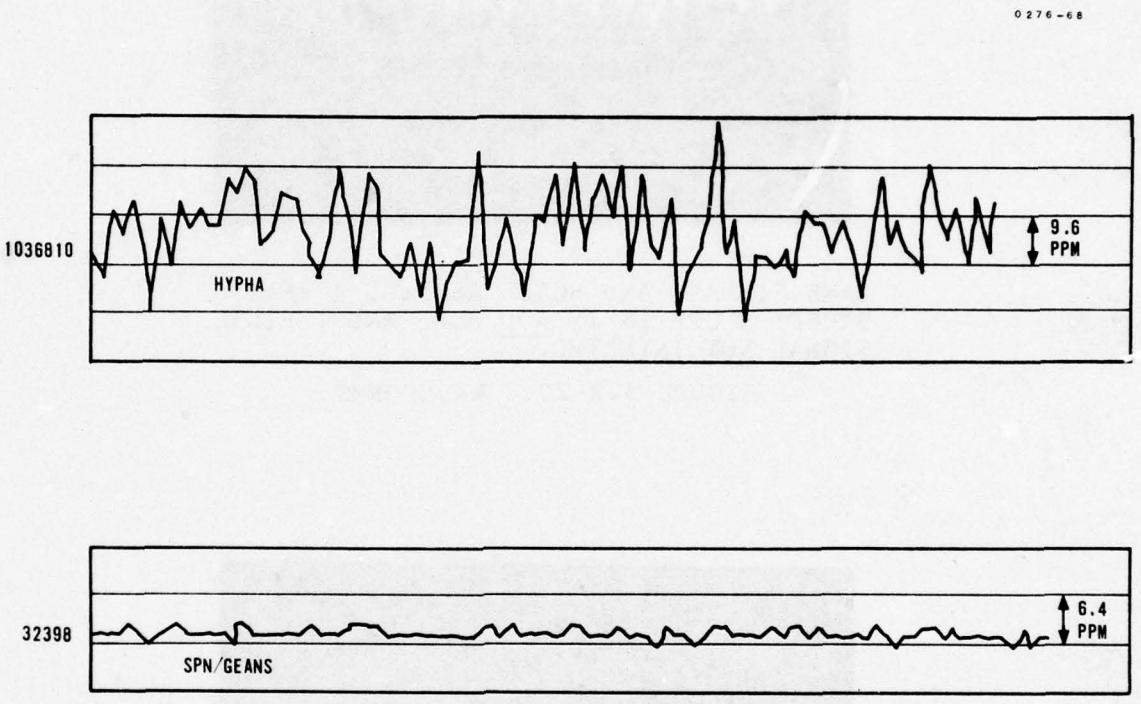


FIGURE 4.2-22. HYPHA LOOP +1g 40 SECOND COUNTS
11-1-74

The testing up to this point was before the work stoppage. At that time, the following problem areas and the corresponding recommendations were stated:

1. Count scatter

   Continue to investigate reason

   Look into transform simulation and analyze noise

2. Gain difference needed for 0g versus 1g

   Investigate reason

3. Sync clock VCO stability problems

   Look into a crystal VCO or other solution

4. DC offsets in the loop

   Investigate, possibly redistribute gains.

Upon resumption of work, each of these areas were resolved as follows:

The effort to reduce count scatter was a continuing one, lasting through the entire development of this loop. As improvements were made in various areas, the scatter was further reduced. The changes made to the loop which improved the scatter were as listed below:

- Improved power and ground distribution.
- Better tuning of VCO center frequency.
- Reduced bandwidth of the loop.
- Changed to a different VCO for the clock system.
- Used new SPN/GEANS brassboard for input data.
- Better matching of pendulum signal to loop error signal.
- Better decoupling of dc power on clock PLL.

After all the above changes, the count scatter was improved to a satisfactory level at all g levels except close to 0g.

Much of the intermediate test data presented at the data review of 9/5/75 will be omitted in this report, since all tests were rerun after the final design changes.

Figure 4.2-23 is a plot of standard deviation of counts taken at 1 degree increments. As seen here the count scatter peaks on each side of 0g. The peak value of deviation before the final modification was approximately 1.5 counts.

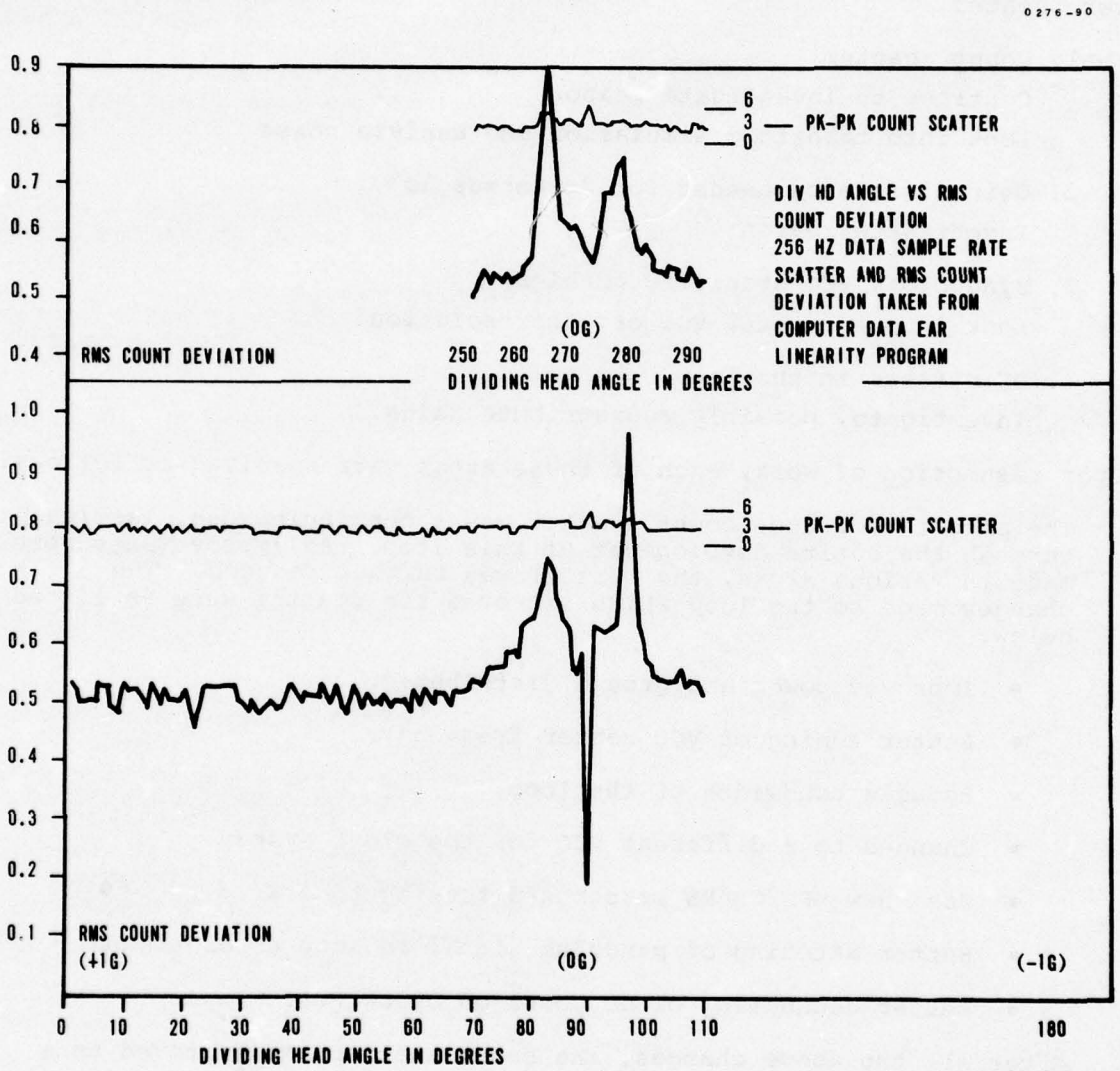


FIGURE 4.2-23. HYPHA INTERPOLATOR - LINEARITY RUN
11-3-75

In order to bring these peaks below the one count requirement, a dither clock was inserted into the pendulum signal (see Figure 4.2-2). It was found that by modulating the pendulum signal with a 256 Hz clock, which is the same frequency as the data sample rate, the count scatter could be reduced. It was deduced that the VCO was locking to noise in the 0g region due to the low level of input. The dither appeared to prevent this lock. Since the dither was at the same frequency as the data sample rate it did not show in the data.

Before the bandwidth of the Hypha loop was lowered to reduce noise, an analysis was performed to evaluate the impact (see Figures 4.2-24 through 4.2-34). This analysis verified that a bandwidth as low as 50 Hz would not impair compliance with EAR requirements. Therefore, the bandwidth was lowered to 50 Hz. Lowering the bandwidth also resolved the problem of needing a different pendulum gain at 1g versus 0g. The explanation for this lies in the fact that much better matching was possible between the pendulum signal and the loop error signal with reduced bandwidth. As for the other problems to be resolved in the Hypha circuit, they were treated as follows. The sync clock phase lock loop stability problem was cured by changing to an LC tuned VCO in place of the original, which was only capacitor tuned. The new VCO has much better noise rejection properties.

The dc offset problem was solved by adding two more bits to the D/A converter and the associated counter/register. This gave the loop more dynamic range to handle the large dc offsets contained in the demod output signal.

All the tests performed on the SPN/GEANS and the HRPWM Loop were run on the Hypha loop. Figure 4.2-35 is a plot of long term stability. Figure 4.2-36 is a plot of the null deadband test data. Figure 4.2-37 gives the linearity data. Tables 4.2-1, 4.2-2 and 4.2-3 are computer typeouts of the same three conditions run on the HRPWM loop, showing count scatter and deviation. Figures 4.2-38, 4.2-39 and 4.2-40 are line printer plots for each of the same three conditions. Tables 4.2-4, 4.2-5 and 4.2-6 are summary sheets showing linearity stability and noise data. Figures 4.2-41 through 4.2-55 are plots of PSD analysis results for each of the three conditions.

SINUSOIDAL VIBRATION

EXCEEDS SPEC FROM .55 TO 1.3 HZ

MAX ERROR = 1.7X SPEC @ 0.7 HZ

RANDOM VIBRATION

50 HZ
20 $\approx$ 1/5 SPEC (CENTERED @ 35 HZ)

100 HZ
20 $\approx$ 1/5 SPEC (CENTERED @ 70 HZ)

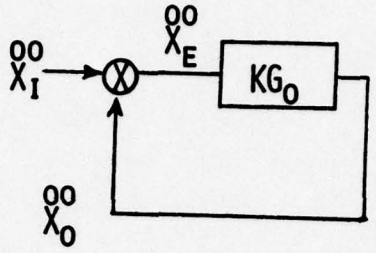
WINDGUST

00 HZ
0 $\approx$ 3/4 SPEC (CENTERED @ 0.6 HZ)

FIGURE 4.2-24. DYNAMIC ERRORS -
50 HZ BW HYPHA LOOP

DEVELOP ERROR TRANSMISSIBILITY V.S. FREQUENCY

$$\frac{\overset{oo}{X_E}}{\overset{oo}{X_I}} = KG_{CL} \times \frac{1}{KG_{OL}}$$



PLOT ACCELERATION INPUT VS FREQUENCY ($\overset{oo}{X_I}$)

SINUSOIDAL INPUT

$$\overset{oo}{X_E} = \overset{oo}{X_I} \quad \frac{KG_{CL}}{KG_{OL}}$$

RANDOM VIBRATION

$$\overset{oo}{X_E}^2 = \overset{oo}{\emptyset_I} \left(\frac{KG_{CL}}{KG_O}\right)^2$$

$\overset{oo}{\emptyset_I}$ = POWER SPECTRAL DENSITY INPUT
= g^2/HZ

$$\overset{oo}{X_E} = \left(\int_{F_1}^{F2} \overset{oo}{\emptyset_I} \left(\frac{KG_{CL}}{KG_{GL}}\right) \right)^{1/2}$$

WIND GUSTS

SAME AS RANDOM - WIND GUST - NOISE CALCULATED FOR 4 F.P.S. VELOCITY

FIGURE 4.2-25. ANALYSIS APPROACH - HYPHA LOOP ERRORS

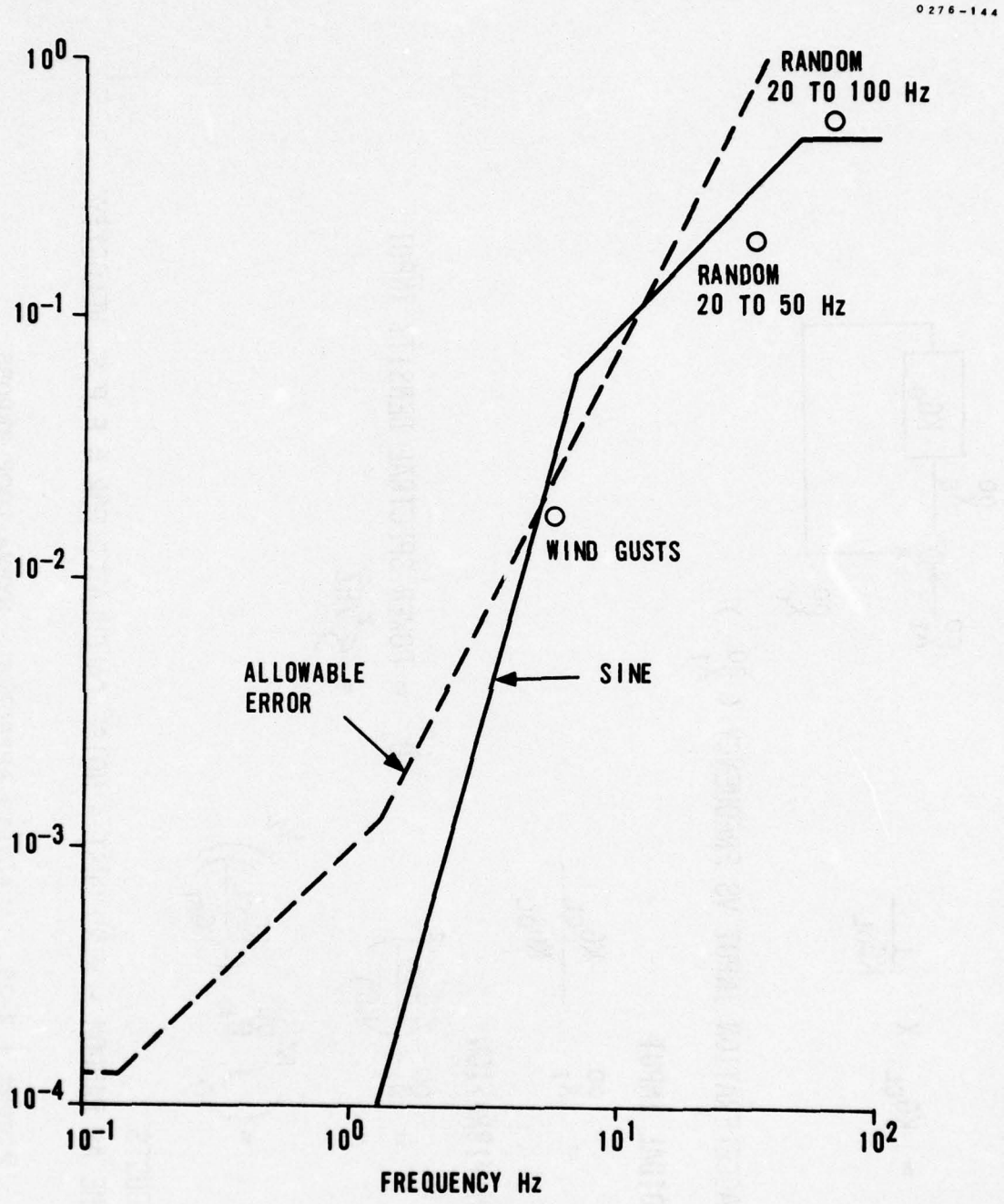


FIGURE 4.2-26. 50 Hz BW HYPHA LOOP DYNAMIC ERRORS COMPARED TO ALLOWABLE ERROR

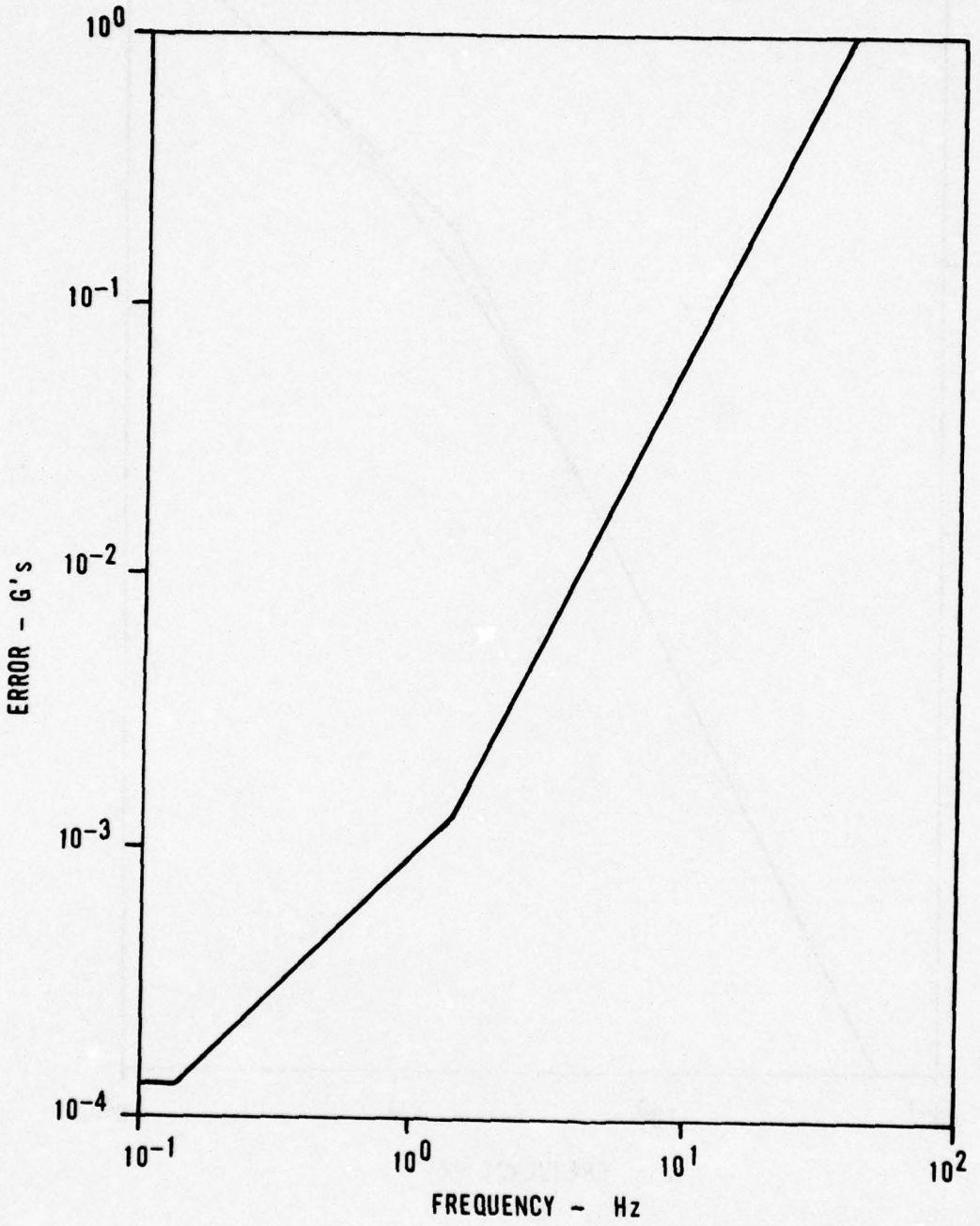


FIGURE 4.2-27. ALLOWABLE ACCELERATION - ERROR VERSUS FREQUENCY

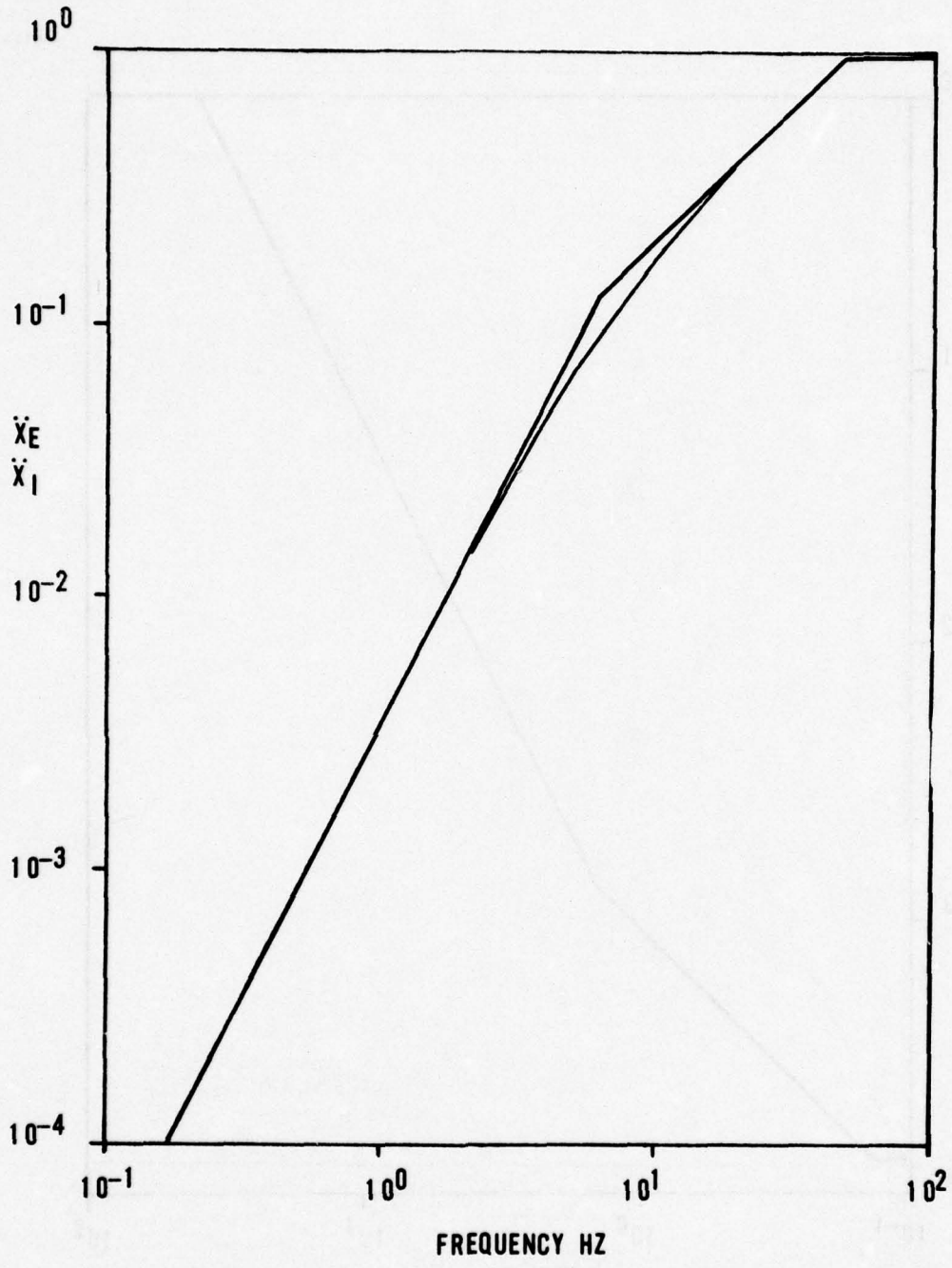


FIGURE 4.2-28. HYPHA LOOP ERROR TRANSMISSIBILITY

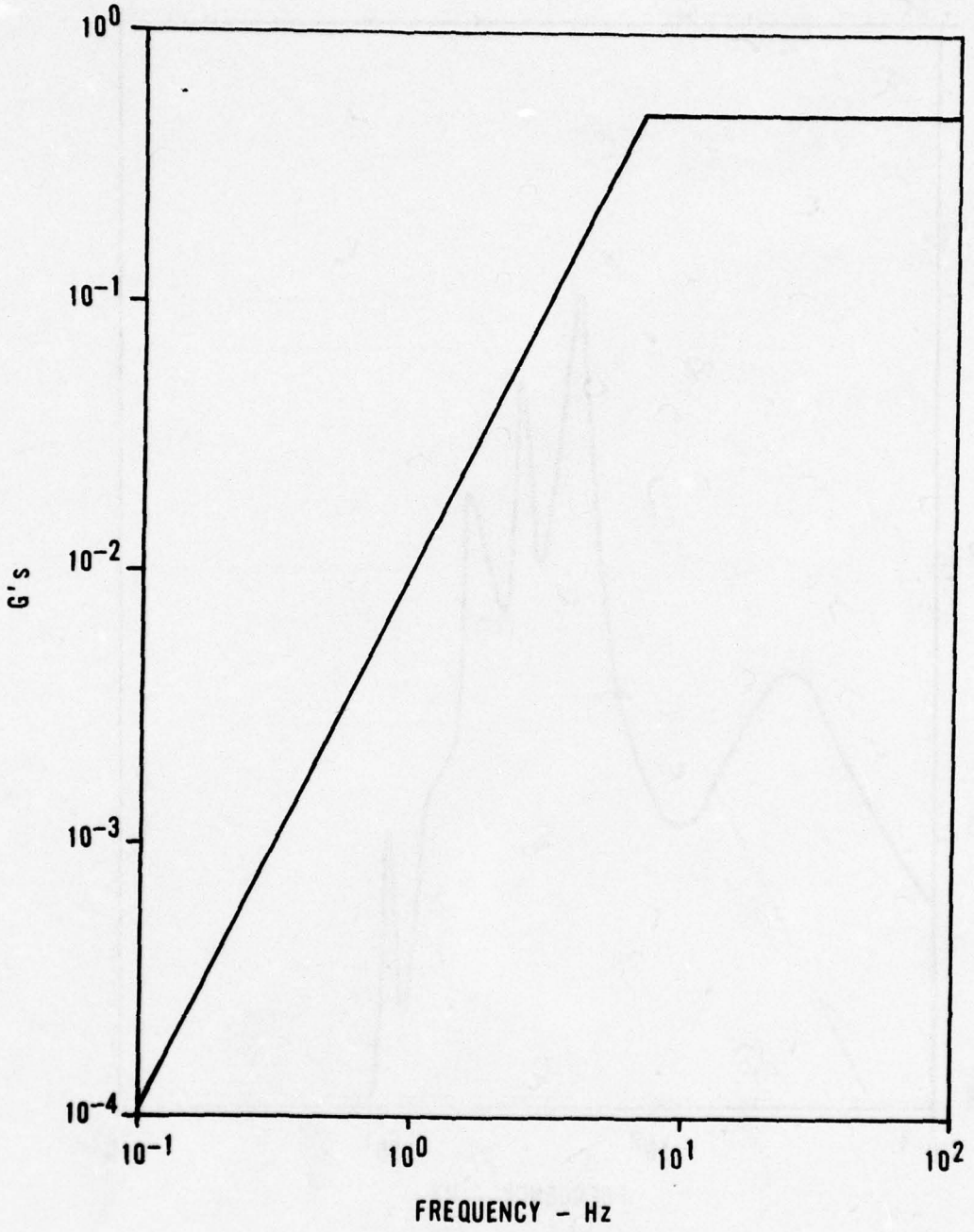


FIGURE 4.2-29. SINE VIBRATION SPECIFICATION

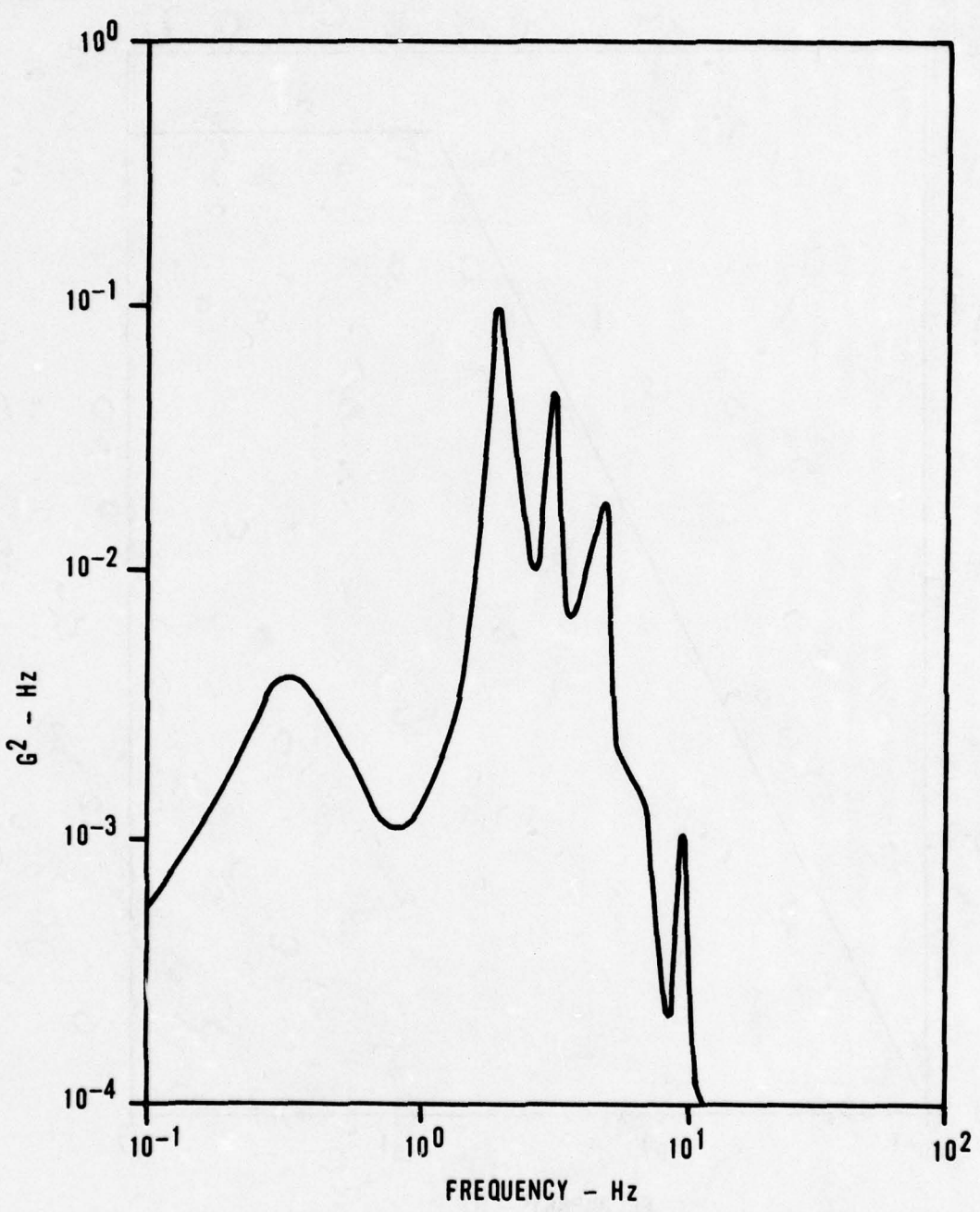
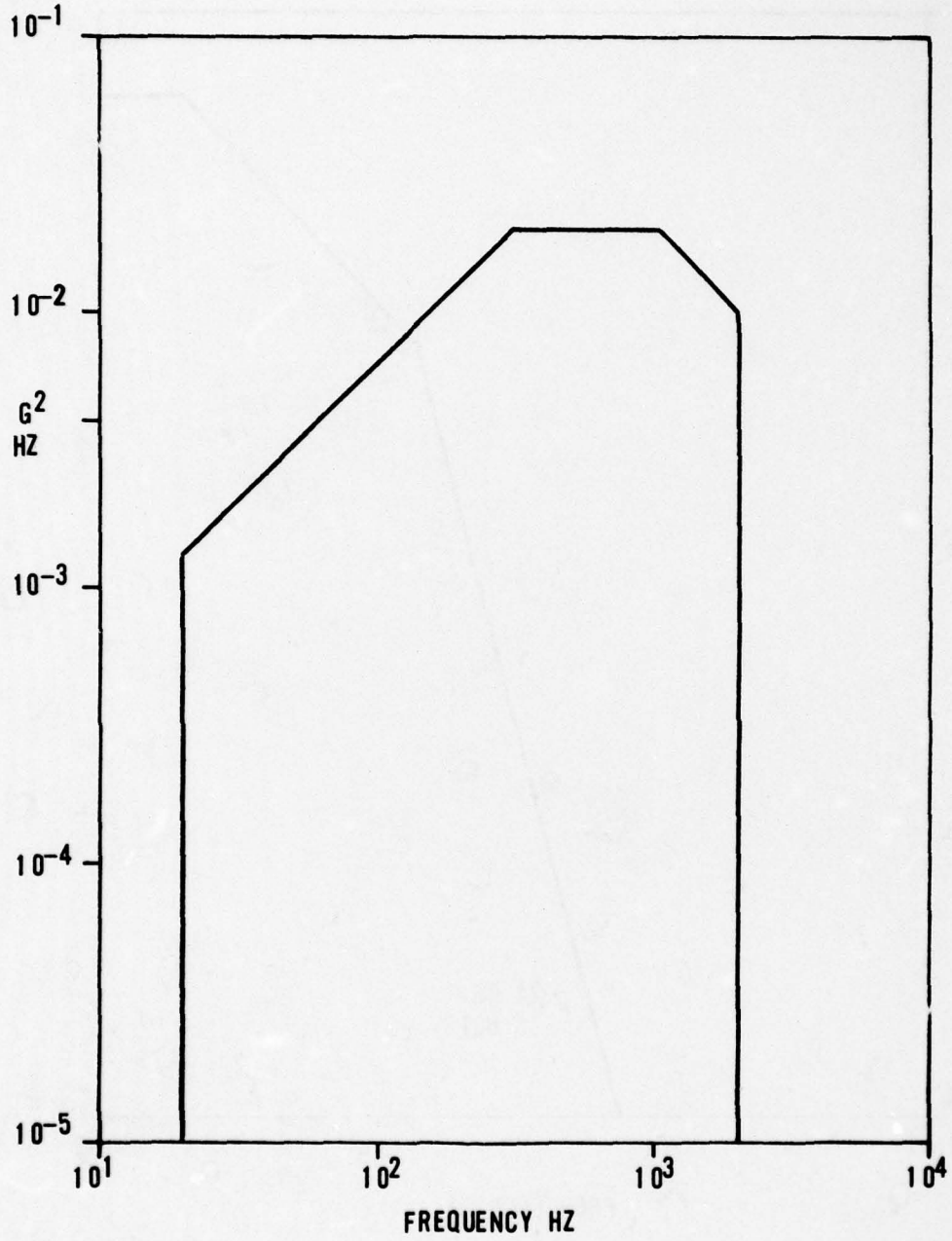


FIGURE 4.2-30. WIND GUST SPECTRAL DENSITY
4 PPS INPUT



FOGIRE 4.2-31. RANDOM VIBRATION SPECIFICATION

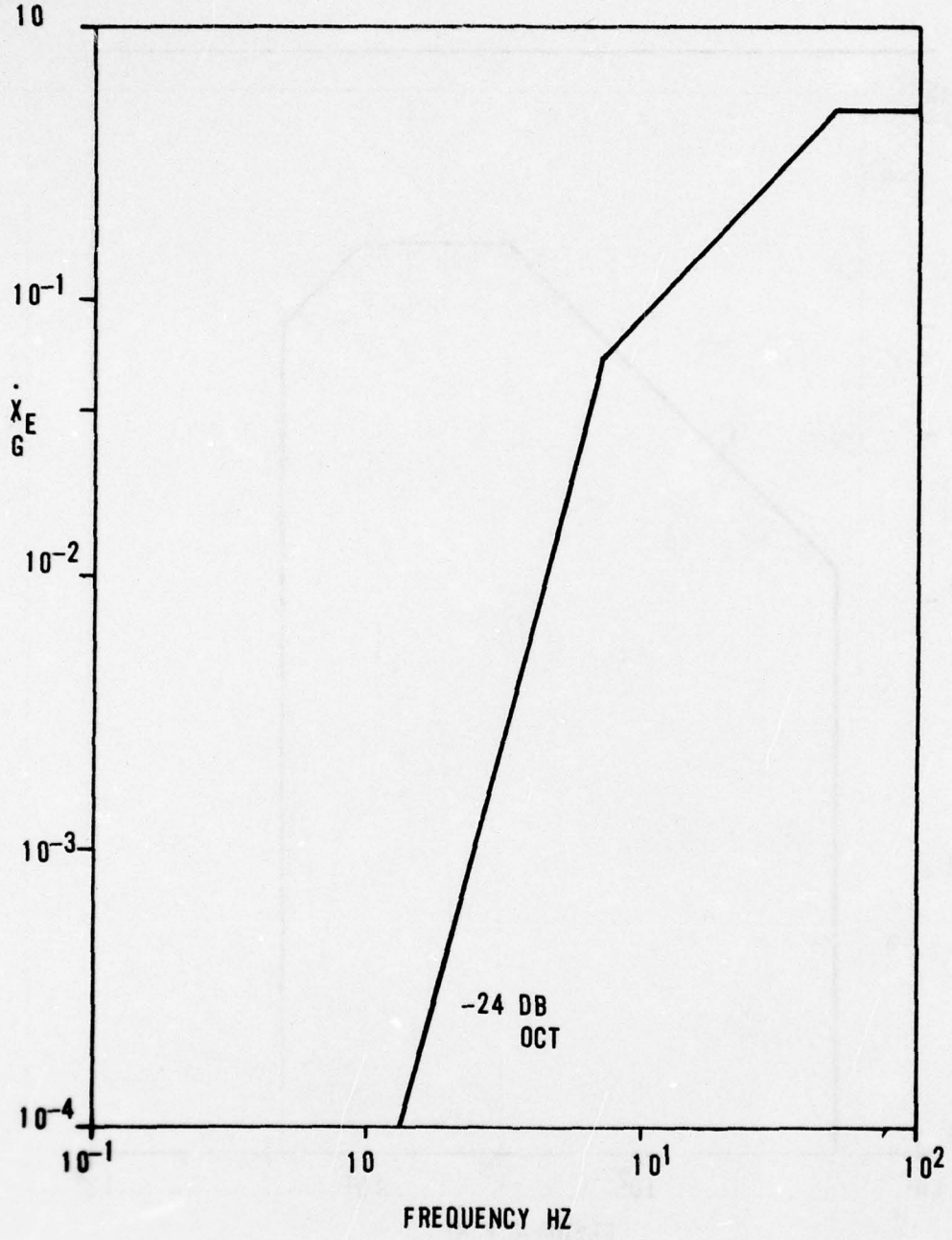


FIGURE 4.2-32. HYPHA LOOP ERROR DUE TO SINUSOIDAL INPUT

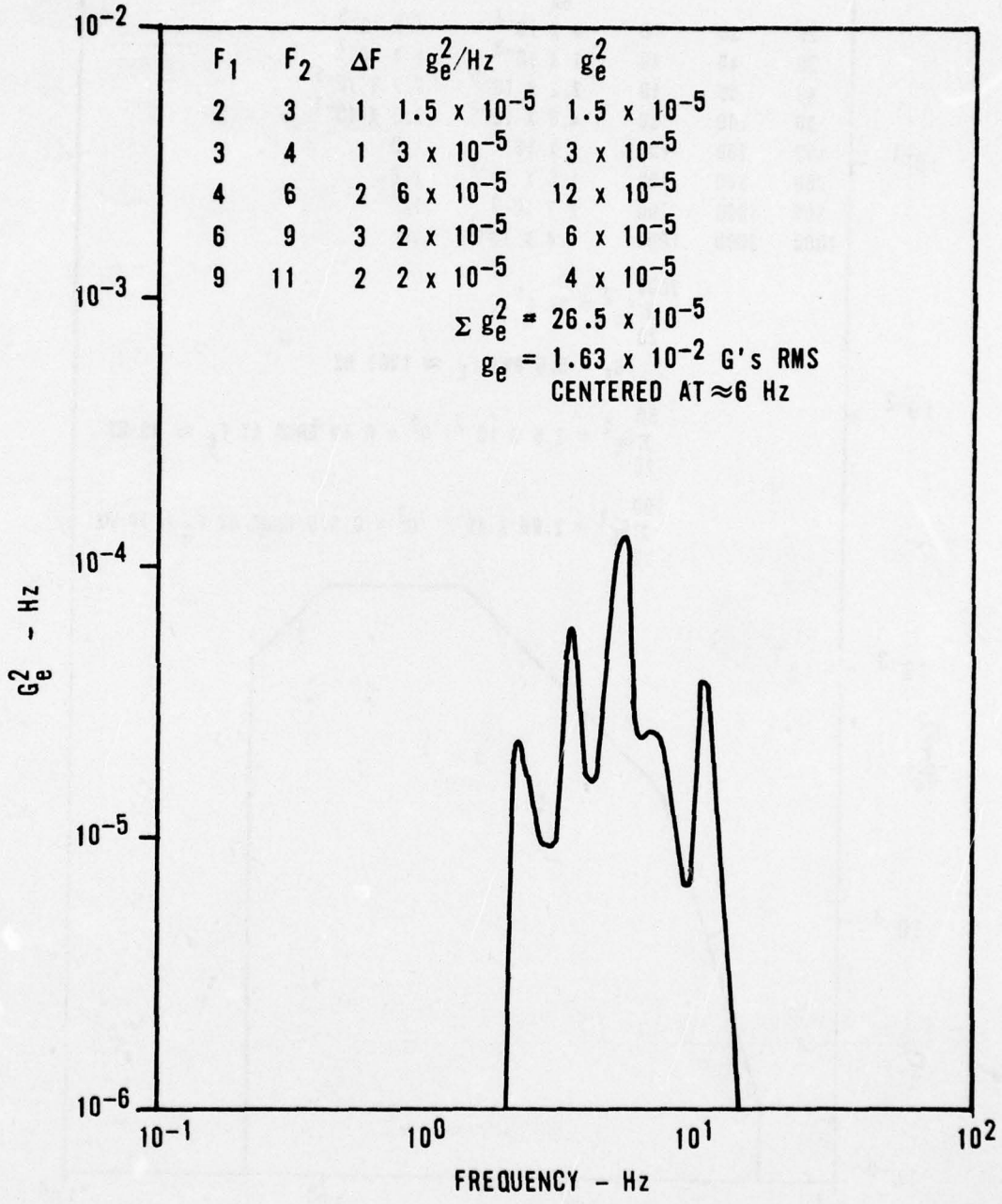


FIGURE 4.2-33. HYPHA LOOP ERRORS DUE TO WIND GUSTS

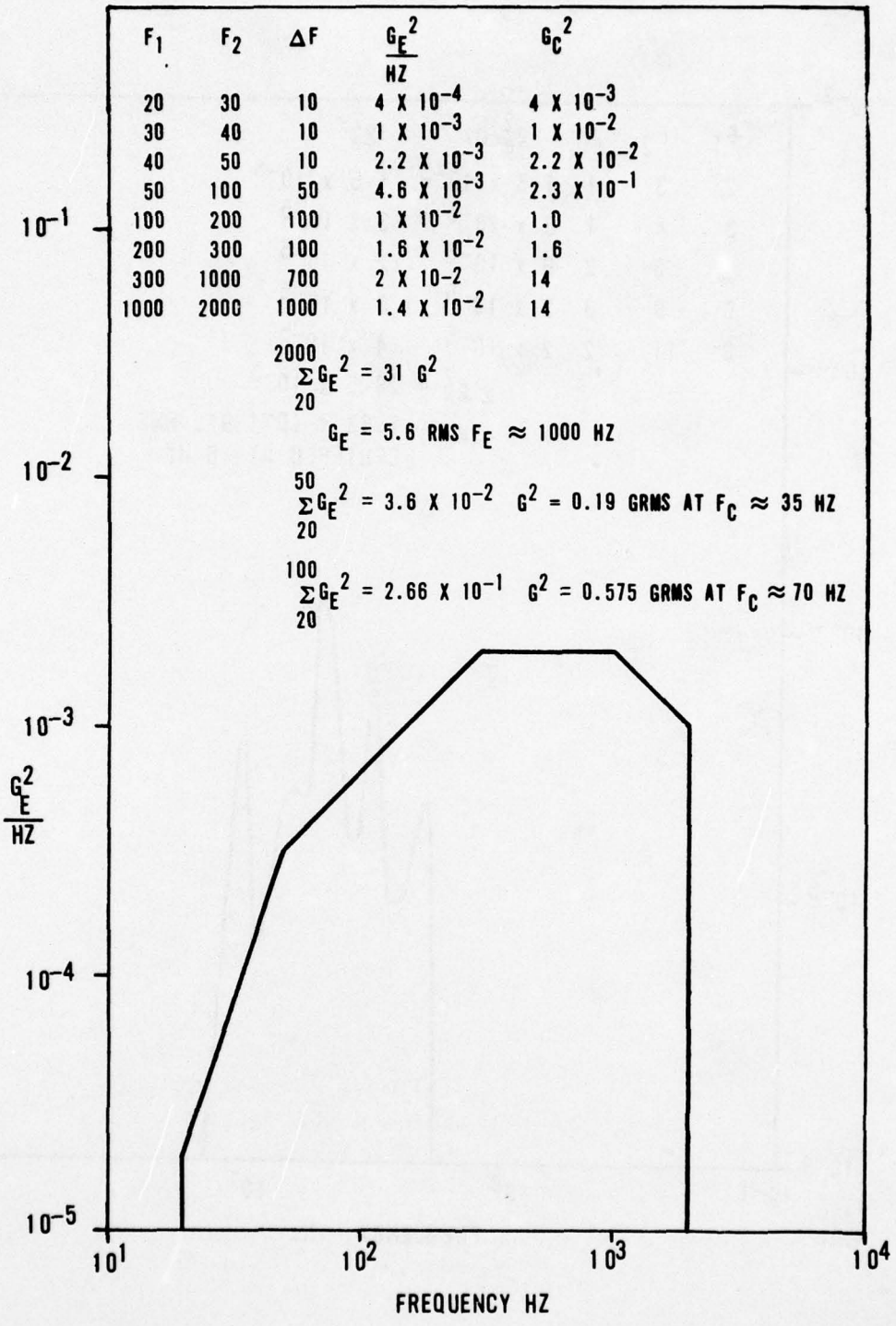


FIGURE 4.2-34. HYPHA LOOP ERROR DUE TO RANDOM VIBRATION INPUT

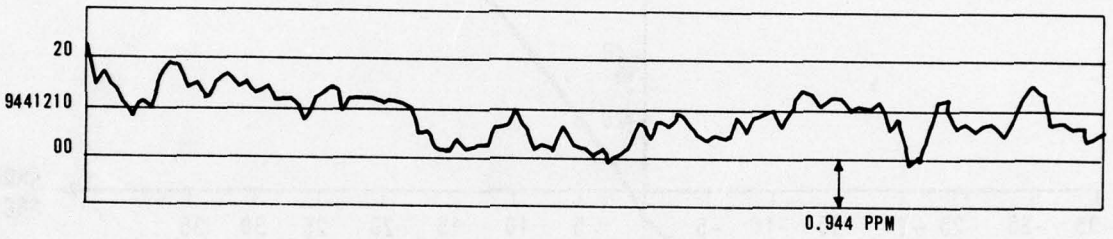


FIGURE 4.2-35. HYPHA LOOP DATA +1G
360 SECOND COUNTS (WITH DITHER)
9-15-75

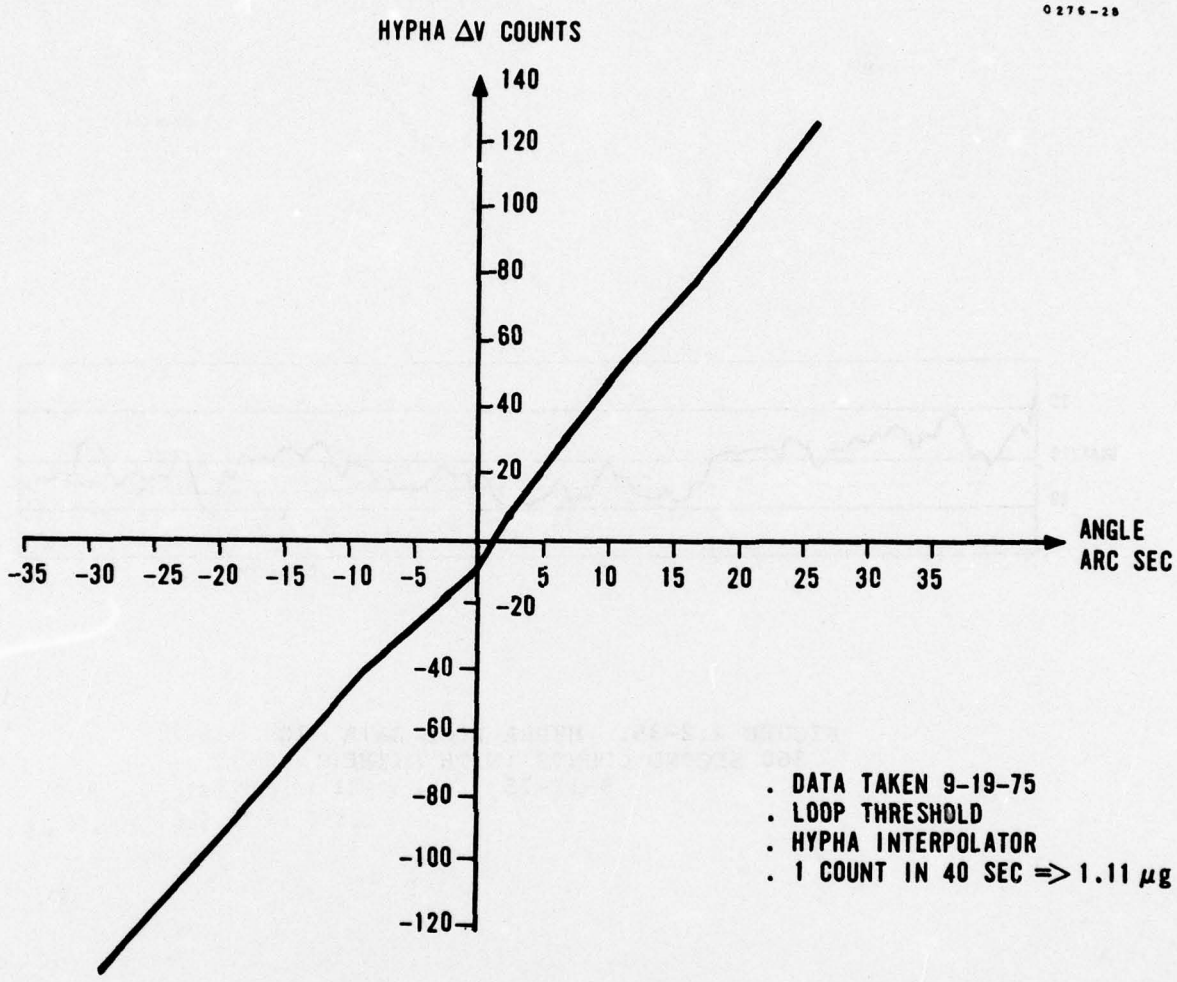


FIGURE 4.2-36. NULL DEADBAND TEST,
EAR LOOP WITH SPN BOARD AND HYPHA 40 SECOND COUNT TIME

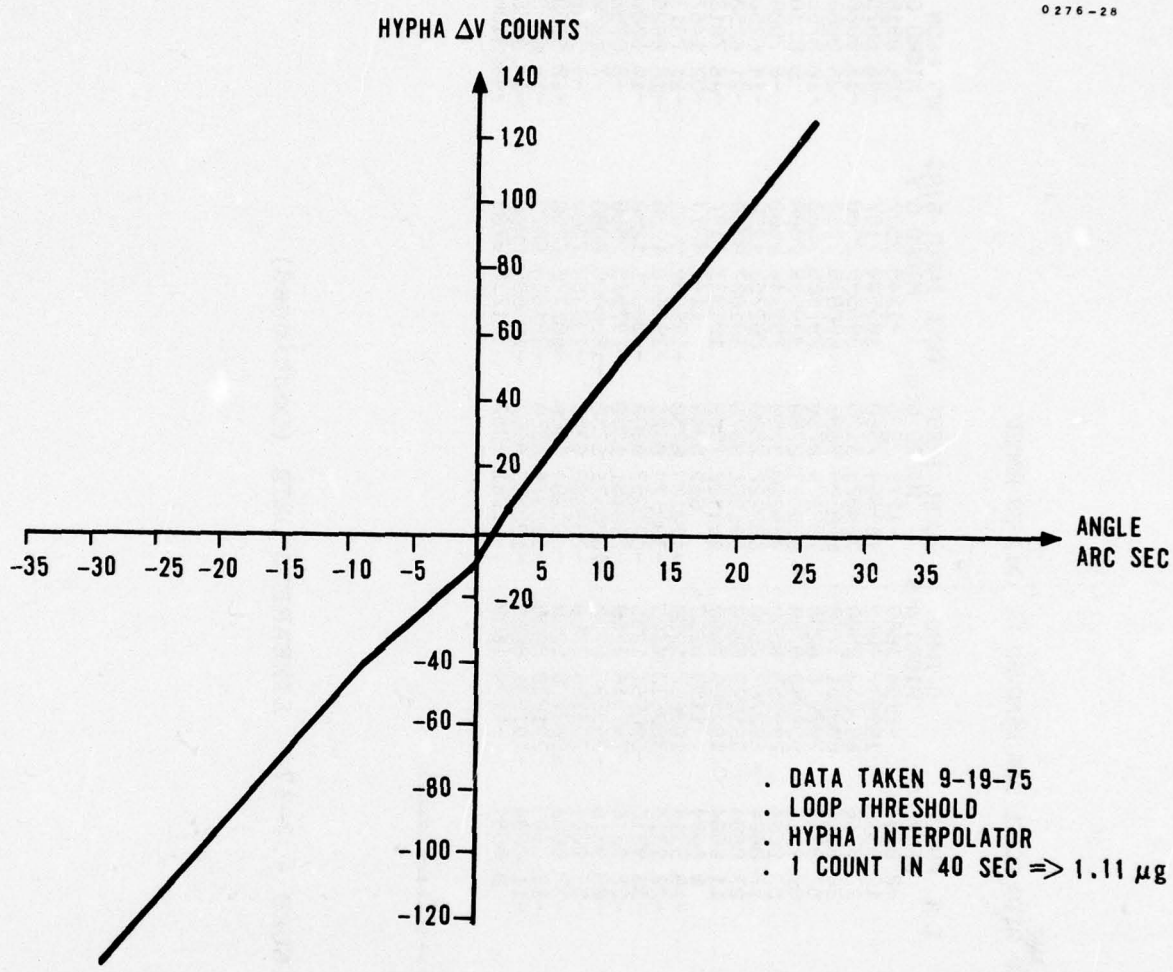


FIGURE 4.2-37. LINEARITY DATA

DEVTATION FROM LINEARITY + - 1G LINE
DG177 S/N V11 HYPHA LOOP WITH ACCEL SIM REMOVED F DITHER ADDED
9/. 75

DIV HEAD ANGLE DEGREES	DELTA V,S COUNTS/ 38. SEC	I.A. ANGLE DEGREES	G INPUT MICRO G'S	ACCEL INPUT MICRO G'S	ACCL INPUT-BIAS MICRO G'S	DEV FROM LIN MICRO G'S
90.0000	1741.0000	-0.0684	-1194.1609	-1771.2295	-1245.2527	-51.0918
101.0000	-185838.0000	10.9316	189637.4062	189064.7500	189590.7187	-46.6875
113.0000	-382433.0000	22.9316	389632.2500	389073.3125	389599.2500	-33.0000
127.0000	-590064.0000	36.9316	600861.3750	600309.5000	600835.3750	-26.0000
143.0000	-783771.0000	52.9316	797916.6250	797379.8750	797905.7500	-10.8750
180.0000	-982416.0000	89.9316	999998.8750	999473.8750	999999.7500	0.8750
217.0000	-785187.0000	53.0684	799353.0000	798820.3750	799346.2500	-6.7500
233.0000	-591949.0000	37.0684	602767.7500	602227.2500	602753.1250	-14.6250
247.0000	-384604.0000	23.0684	391829.5000	391281.9375	391807.8750	-21.6250
259.0000	-188141.0000	11.0684	191980.5000	191407.7500	191933.7187	-46.7813
270.0000	-605.0000	0.0684	1193.6282	615.5048	1141.4814	-52.1467
281.0000	186939.0000	-10.9316	-189637.1250	-190184.8750	-189658.9062	-21.7813
293.0000	383515.0000	-22.9316	-389632.0625	-390174.0625	-389648.1250	-16.0625
307.0000	591133.0000	-36.9316	-600861.1250	-601397.0000	-600871.1250	-10.0000
323.0000	784824.0000	-52.9316	-797916.3750	-798451.1250	-797925.2500	-8.8750
360.0000	983456.0000	-89.9316	-999998.8750	-1000531.8750	-1000006.0000	-7.1250
37.0000	786237.0000	-53.0684	-799353.3750	-799888.6250	-799362.7500	-9.3750
53.0000	593008.0000	-37.0684	-602768.1250	-603304.5000	-602778.6250	-10.5000
67.0000	385678.0000	-23.0684	-391830.0000	-392374.6250	-391848.6875	-18.6875
79.0000	189248.0000	-11.0684	-191981.0625	-192533.9687	-192008.0000	-26.9375
90.0000	1731.0000	-0.0684	-1194.1609	-1761.0557	-1235.0789	-40.9180

********** LINEAR VERSION **********

FIGURE 4.2-37. LINEARITY DATA (Continued)

```
 POS1 =      1741.
 POS2 =   -982416.
 POS3 =      -605.
 POS4 =    983450.
   DT =        38.  SECONDS
 BIAS (1G) =   -525.977 MICRO G,S
BIAS (0G) =   -577.862 MICRO G,S
BIAS COMPENSATION =     51.885 MICRO G,S
ANGLE =  -1193.367MICRO RADIANS
 CORR =   1.000000
 SCALE FACTOR = =26211.546PULSES/SEC/G
  DHC =  90.068375

  MEAN DEVIATION FROM LINEAR =   -22.8080 MICRO G,S
  RMS OF DEV+ATION FROM MEAN =    15.8773 MICRO G,S
           DEVIATION (RMS) =    27.7902 MICRO G,S

********** LINEAR VERSION **********
```

```
 SUM(X(I)/N)
SQRT ((SUM(X(I)SQ/N) - (MEAN)SQ
SQRT (SUM (X(I)SQ)/N)
```

FIGURE 4.2-37. LINEARITY DATA (Continued)

DEVIATION FROM LINEARITY + - 1G LINE
DG177 S/N V11 HYPHA LOOP WITH ACCEL SIM REMOVED AND DITHER ADDED
9/16/75

DIV HEAD ANGLE DEGREES	DELTA V,S COUNTS/ 38. SEC	I.A. ANGLE DEGREES	G INPUT MICRO G'S	ACCEL INPUT MICRO G'S	ACCL INPUT-BIAS MICRO G'S	DEV FROM LIN MICRO G'S
90.0000	1741.0000	-0.0684	-1194.1609	-1771.2295	-1193.4292	0.7317
101.0000	-185838.0000	10.9316	189637.4062	189064.7500	189632.7500	-4.6563
113.0000	-382433.0000	22.9316	389632.2500	389073.3125	389630.9375	-1.3125
127.0000	-590064.0000	36.9316	600861.3750	600309.5000	600856.1250	-5.2500
143.0000	-783771.0000	52.9316	797916.6250	797379.8750	797916.2500	-0.3750
180.0000	-982416.0000	89.9316	999998.8750	999473.8750	999999.7500	0.8750
217.0000	-785187.0000	53.0684	799353.0000	798820.3750	799356.7500	3.7500
233.0000	-591949.0000	37.0684	602767.7500	602227.2500	602773.7500	6.0000
247.0000	-384604.0000	23.0684	391829.5000	391281.9375	391839.4375	9.9375
259.0000	188141.0000	11.0684	191980.5000	191407.7500	191975.6250	-4.8750
270.0000	-605.0000	0.0684	1193.6282	615.5048	1193.3052	-0.3230
281.0000	186939.0000	-10.9316	-189637.1250	-190184.8750	-189616.8750	20.2500
293.0000	383515.0000	-22.9316	-389632.0625	-390174.0625	-389616.4375	15.6250
307.0000	591133.0000	-36.9316	-600861.1250	-601397.0000	-600850.3750	10.7500
323.0000	784824.0000	-52.9316	-797916.3750	-798451.1250	-797914.7500	1.6250
360.0000	983456.0000	-89.9316	-999998.8750	-1000531.8750	-1000006.0000	-7.1250
37.0000	786237.0000	53.0684	-799353.3750	-799888.6250	-799352.2500	1.1250
53.0000	593008.0000	37.0684	-602768.1250	-603304.5000	-602758.0000	10.1250
67.0000	385678.0000	23.0684	-391830.0000	-392374.6250	-391817.1250	12.8750
79.0000	189248.0000	-11.0684	-191981.0625	-192533.9687	-191966.0937	14.9688
90.0000	1731.0000	-0.0684	-1194.1609	-1761.0557	-1183.2554	10.9055

********** G**2 VERSION **********

FIGURE 4.2-37. LINEARITY DATA (Continued)

```
 POS1 =       1742.
 POS2 =    -982418.
 POS3 =       -606.
 POS4 =     983460.
   DT =       1200.  SECONDS
 BIAS (1G) =    -530.043 MICRO G,S
BIAS (0G) =    -577.859 MICRO G,S
BIAS COMPENSATION =      47.816 MICRO G,S
ANGLE =  -1194.377MICRO RADIANS
 CORR =   1.000000
 SCALE FACTOR =  -819.1158PULSES/SEC/G
  DHC =  90.068420

  MEAN DEVIATION FROM LINEAR =    -19.2910 MICRO G,S
  RMS OF DEV+ATION FROM MEAN =     15.6481 MICRO G,S
             DEVIATION (RMS) =     24.8396 MICRO G,S

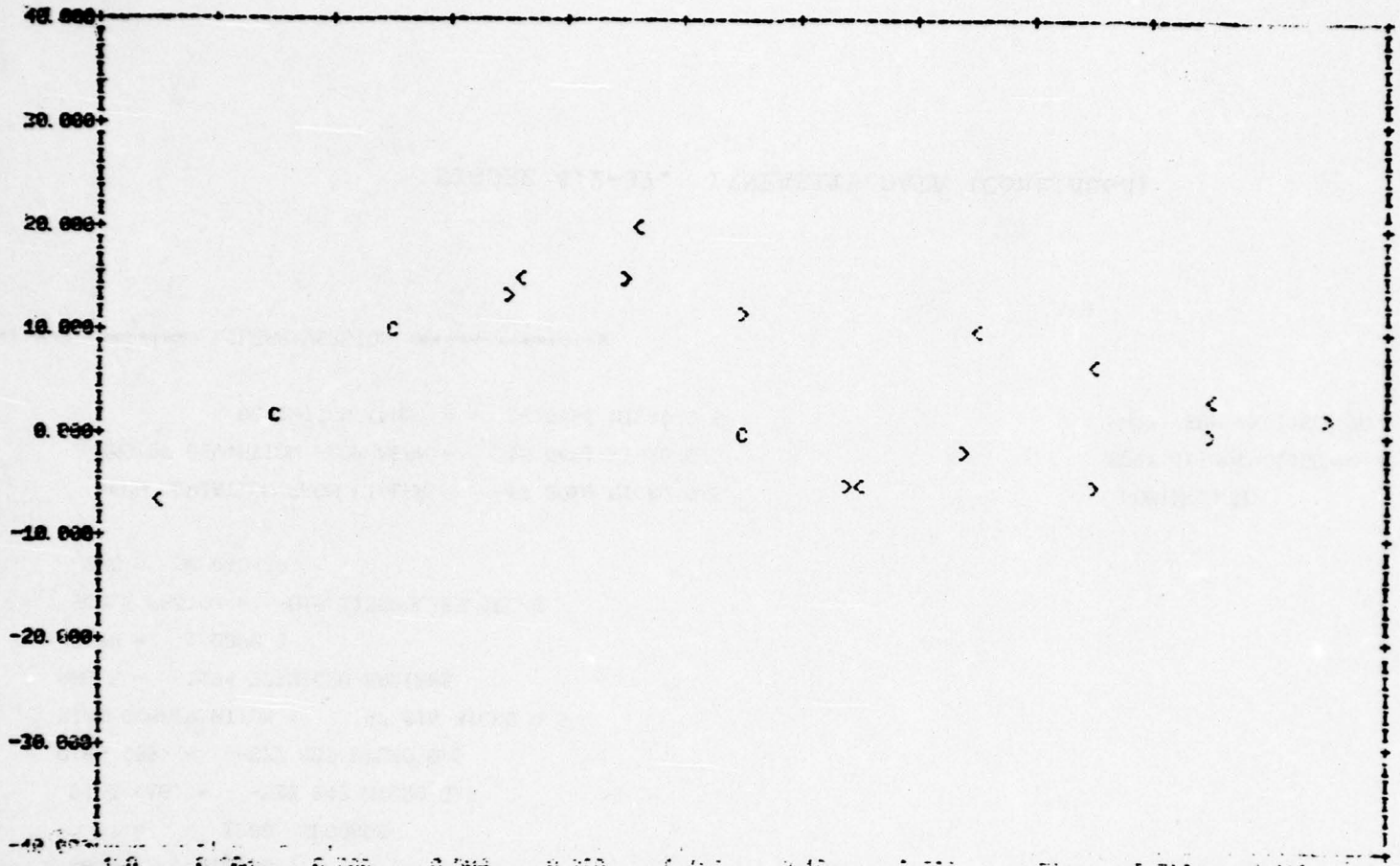
********** LINEAR VERSION **********
```

SUM(X(I)/N)

SQRT ((SUM(X(I)SQ/N) - (MEAN)SQ)

SQRT (SUM (X(I)SQ)/N)

FIGURE 4.2-37. LINEARITY DATA (Continued)



ACCELEROMETER SCALE FACTOR DEVIATION FROM LINEAR IN MICRO G'S VS.
INPUT ACCELERATION IN G'S
THE DEVIATION IS MEASURED FROM A SCALE FACTOR CALCULATED
USING THE +1G AND -1G DELTA V COUNTS
DG177 S/N Y11 HYPHA LOOP WITH ACCEL SIM REMOVED AND DITHER ADDED
9/16/75

********** G**2 VERSION **********

FIGURE 4.2-37. LINEARITY DATA (Continued)

TABLE 4.2-1. HYPHA LOOP DATA
1 PULSE = 0.00125 FT/SEC

RECD	MAX	MIN	MEAN	DEV
1	1	-3	0.02344	0.21065
2	2	-2	0.02344	0.20596
3	3	-2	0.02539	0.24475
4	3	-2	0.03027	0.20743
5	2	-1	0.03418	0.22054
6	3	-2	0.03418	0.25350
7	2	-3	0.02539	0.24475
8	2	-1	0.03223	0.19248
9	2	-2	0.02441	0.18851
10	1	-2	0.02051	0.17278
11	3	-2	0.03125	0.22750
12	2	-2	0.02637	0.19337
13	5	-2	0.04102	0.30019
14	2	-1	0.02930	0.19040
15	2	-2	0.02539	0.21042
16	2	-2	0.02637	0.19835
17	2	-3	0.02539	0.24073
18	2	-2	0.02832	0.21236
19	2	-3	0.02246	0.23067
20	2	-1	0.02637	0.19337
21	2	-2	0.02734	0.20067
22	2	-2	0.01855	0.20881
23	2	-4	0.02148	0.22863
24	4	-1	0.02734	0.23225
25	3	-3	0.01855	0.28410
26	3	-2	0.03027	0.22977
27	2	-1	0.02539	0.16927
28	2	-2	0.02637	0.25443
29	2	-6	0.02148	0.26057
30	1	-3	0.02344	0.18603
31	2	-4	0.02734	0.24051
32	1	-1	0.02734	0.16897
33	1	0	0.02832	0.16589
34	3	-3	0.02734	0.23225
35	1	-1	0.02734	0.17465
36	1	-1	0.02441	0.17227
37	3	-3	0.02637	0.21261
38	1	-1	0.02637	0.17198
39	1	-2	0.02051	0.18898
40	4	-2	0.04395	0.30781
41	2	-2	0.02539	0.21042
42	3	-2	0.02832	0.21236
43	2	-2	0.02734	0.22368
44	2	-2	0.02148	0.19144
45	4	-3	0.02734	0.26743
46	2	-4	0.01953	0.23304
47	3	-2	0.02539	0.22823
48	2	-1	0.02441	0.17785
49	2	-1	0.03223	0.19248
50	2	-2	0.02637	0.23025

TABLE 4.2-2. HYPHA LOOP DATA
1 PULSE = 0.00125 FT/SEC

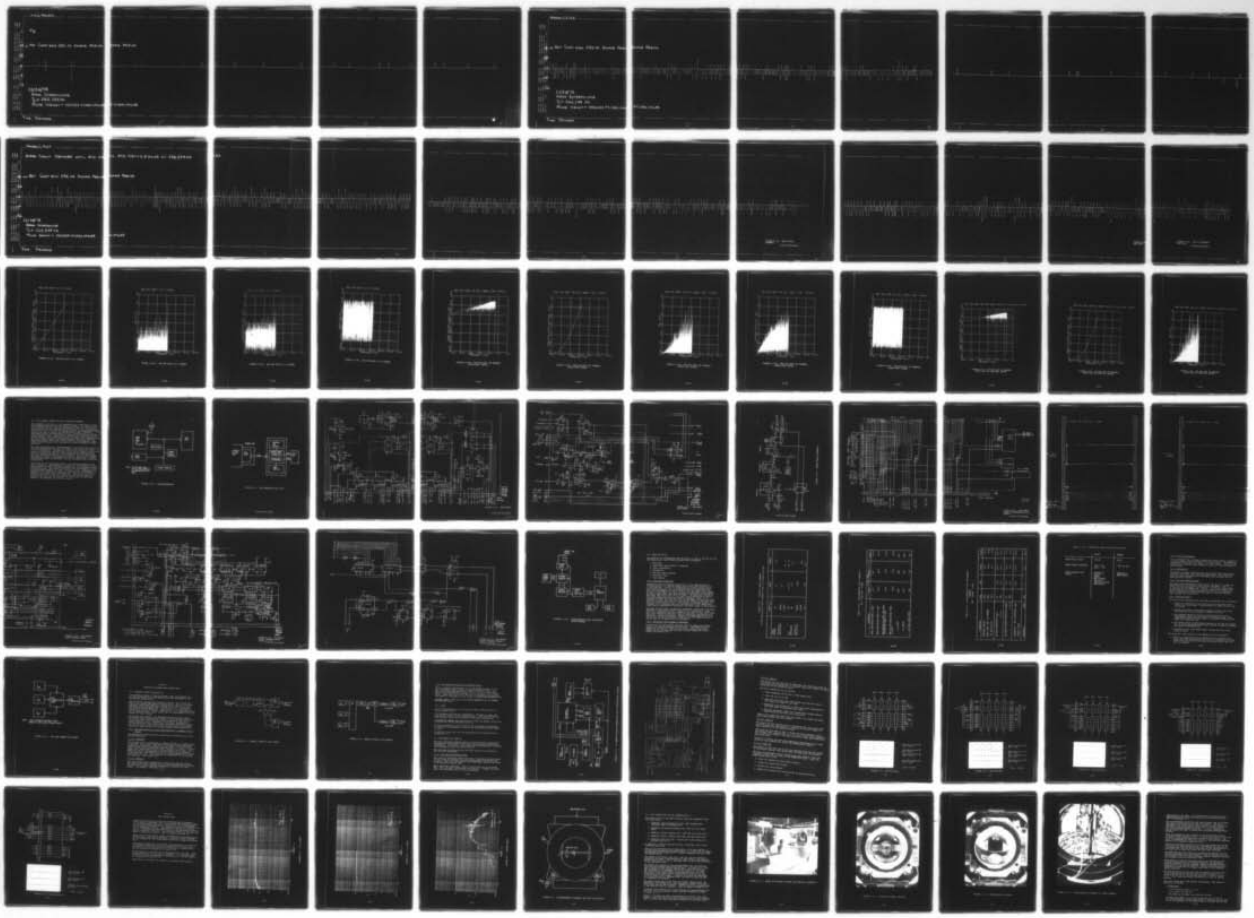
RECD	MAX	MIN	MEAN	DEV
1	-10	-15	-12.45703	0.83859
2	-10	-15	-12.45410	0.88380
3	-10	-15	-12.45605	0.92387
4	-10	-14	-12.45703	0.87059
5	-10	-14	-12.45703	0.89055
6	-10	-15	-12.45508	0.89483
7	-10	-14	-12.45703	0.86946
8	-10	-15	-12.45703	0.88615
9	-9	-15	-12.45410	0.90455
10	-10	-15	-12.45703	0.89164
11	-9	-15	-12.45703	0.89055
12	-10	-15	-12.45703	0.87171
13	-10	-15	-12.45313	0.86926
14	-10	-15	-12.45801	0.87734
15	-10	-15	-12.45410	0.90886
16	-10	-14	-12.45703	0.88615
17	-10	-15	-12.45605	0.86265
18	-10	-15	-12.45801	0.87622
19	-10	-15	-12.45410	0.88490
20	-10	-15	-12.45703	0.89274
21	-10	-15	-12.45605	0.91110
22	-10	-15	-12.45508	0.86147
23	-9	-15	-12.45801	0.87063
24	-10	-14	-12.45508	0.85692
25	-9	-15	-12.45703	0.86043
26	-10	-15	-12.45605	0.86152
27	-10	-15	-12.45508	0.90890
28	-10	-15	-12.45605	0.90140
29	-10	-15	-12.45508	0.89483
30	-10	-15	-12.45703	0.89601
31	-10	-15	-12.45703	0.89055
32	-9	-15	-12.45605	0.88610
33	-10	-15	-12.45605	0.87947
34	-10	-15	-12.45605	0.87501
35	-10	-15	-12.45605	0.90680
36	-10	-14	-12.45605	0.91751
37	-10	-15	-12.45605	0.87390
38	-9	-15	-12.45801	0.89824
39	-10	-15	-12.45410	0.88600
40	-10	-14	-12.45703	0.90145
41	-10	-15	-12.45410	0.90347
42	-10	-15	-12.45703	0.90469
43	-10	-14	-12.45605	0.89597
44	-10	-15	-12.45605	0.88720
45	-10	-15	-12.45605	0.88168
46	-10	-14	-12.45703	0.88505
47	-10	-14	-12.45508	0.89264
48	-10	-14	-12.45703	0.86496
49	-10	-15	-12.45508	0.88605
50	-10	-15	-12.45703	0.89164

TABLE 4.2-3. HYPHA LOOP DATA
1 PULSE = 0.00125 FT/SEC

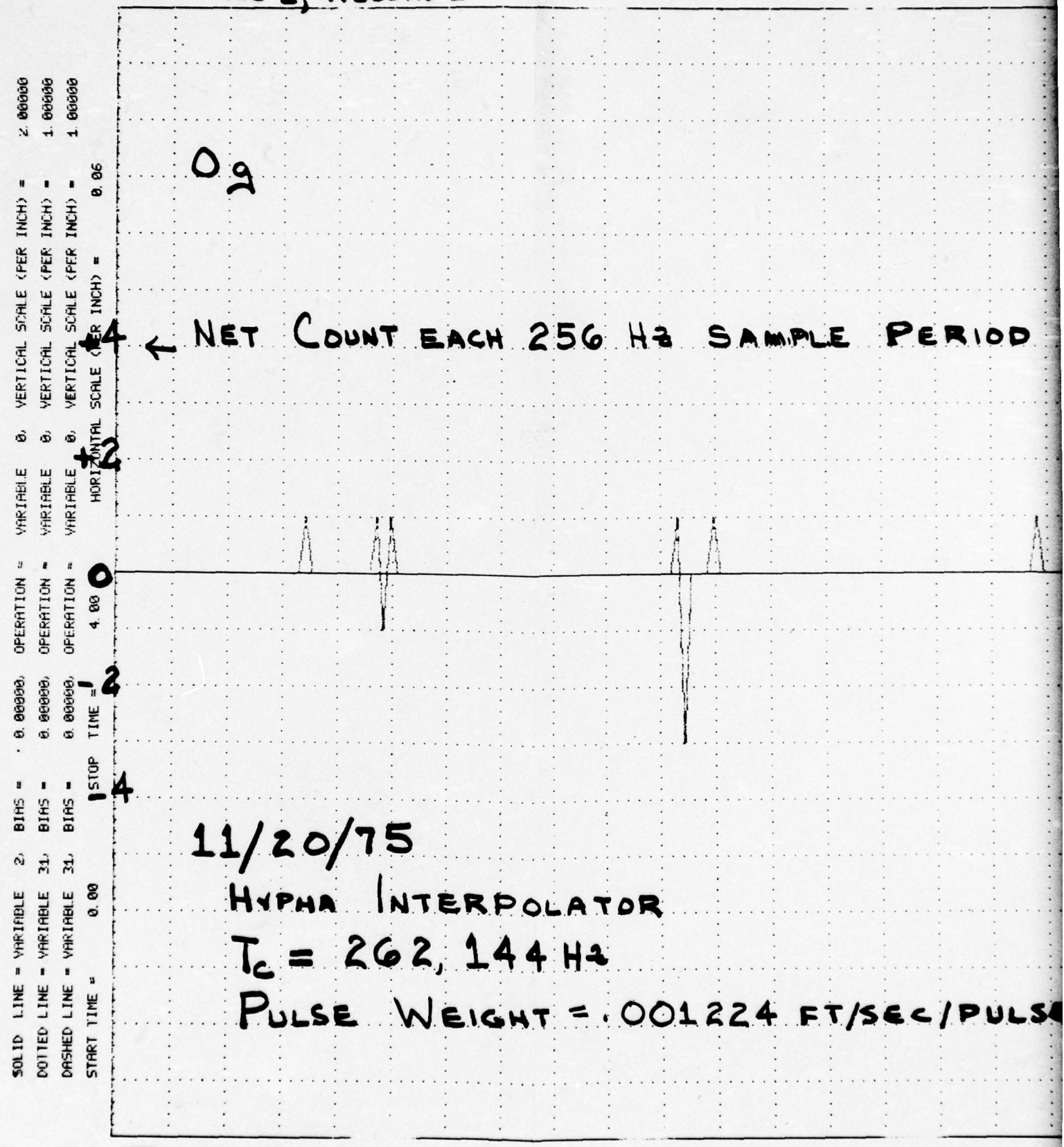
RECD	MAX	MIN	MEAN	DEV
1	-10	-15	-12.45801	1.02517
2	-9	-15	-12.45508	1.03169
3	-9	-15	-12.45605	1.02984
4	-10	-15	-12.45605	1.02031
5	-10	-15	-12.45605	1.05606
6	-10	-15	-12.45508	1.07979
7	-10	-15	-12.45703	1.05794
8	-10	-15	-12.45508	1.06063
9	-9	-15	-12.45508	1.08250
10	-10	-15	-12.45703	1.10579
11	-10	-15	-12.45703	1.03650
12	-10	-15	-12.45508	1.05045
13	-10	-15	-12.45410	1.06701
14	-10	-15	-12.45801	1.06443
15	-10	-15	-12.45605	1.02699
16	-10	-15	-12.45410	1.07067
17	-10	-15	-12.45508	1.00775
18	-10	-15	-12.45801	1.05891
19	-10	-15	-12.45605	1.02794
20	-9	-15	-12.45508	1.08070
21	-10	-15	-12.45703	1.02322
22	-10	-15	-12.45703	1.06071
23	-10	-15	-12.45313	1.06880
24	-10	-15	-12.45703	1.03838
25	-10	-15	-12.45703	1.08438
26	-10	-15	-12.45410	1.06335
27	-10	-15	-12.45508	1.04859
28	-10	-15	-12.45898	1.05802
29	-10	-15	-12.45410	1.02500
30	-9	-15	-12.45605	1.07983
31	-10	-16	-12.45605	1.00973
32	-10	-15	-12.45703	1.05239
33	-10	-15	-12.45410	1.05782
34	-10	-15	-12.45703	1.04588
35	-9	-15	-12.45703	1.03744
36	-10	-15	-12.45410	1.08606
37	-10	-15	-12.45605	1.04116
38	-10	-15	-12.45703	1.04307
39	-10	-15	-12.45703	1.04401
40	-10	-15	-12.45410	1.05041
41	-10	-15	-12.45508	1.02980
42	-10	-15	-12.45801	1.07629
43	-10	-15	-12.45508	1.02600
44	-10	-15	-12.45410	1.05134
45	-10	-15	-12.45801	1.06259
46	-10	-15	-12.45605	1.06435
47	-9	-15	-12.45410	1.05227
48	-10	-15	-12.45801	1.04124
49	-9	-15	-12.45801	1.07083
50	-10	-15	-12.45313	1.03538

AD-A035 033 HONEYWELL INC ST PETERSBURG FLA AEROSPACE DIV F/G 17/7
STANDARD PRECISION NAVIGATOR/GEANS MODIFICATIONS FOR EAR MOTION--ETC(U)
NOV 76 D GIONET, P E HALL, S SAMSEL F33615-74-C-1068
UNCLASSIFIED 176-13551 AFAL-TR-76-71 NL

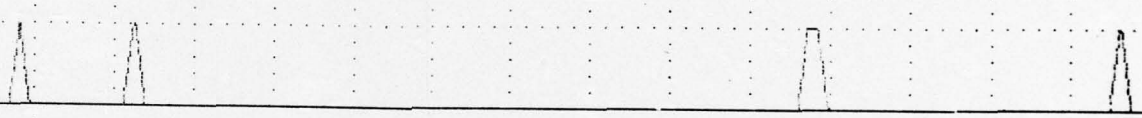
3 OF 5
AD A035033



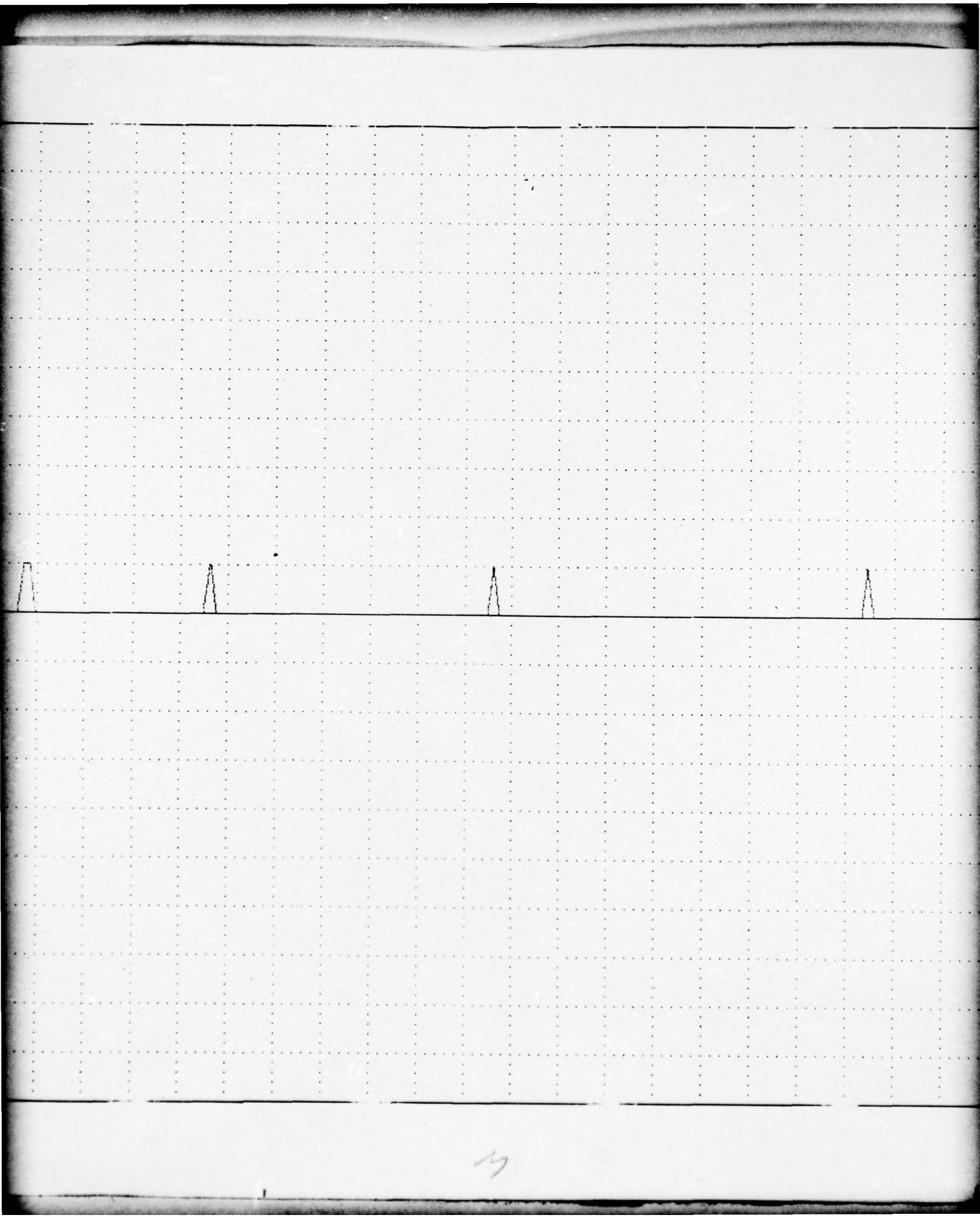
FILE 1, RECORD 1

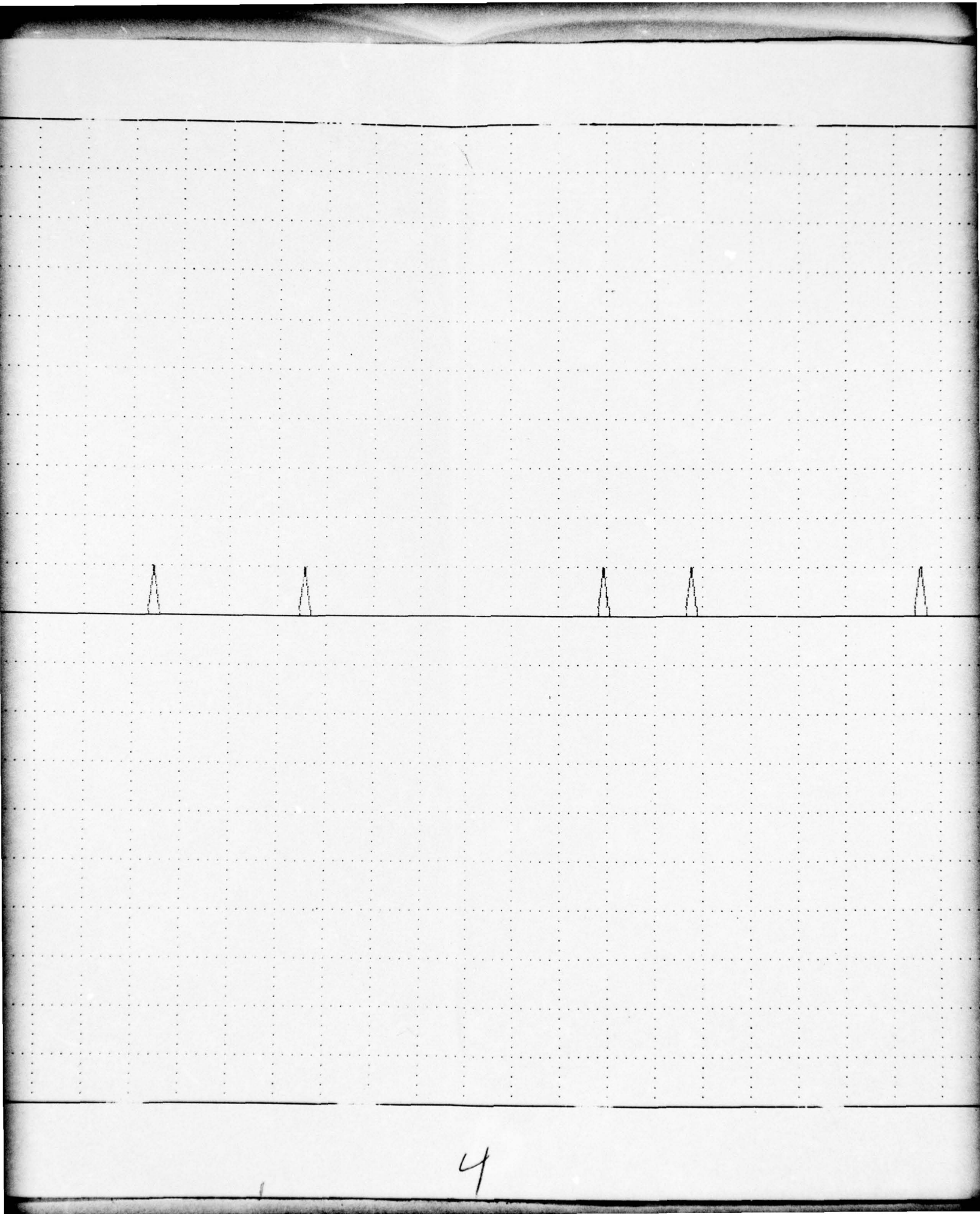


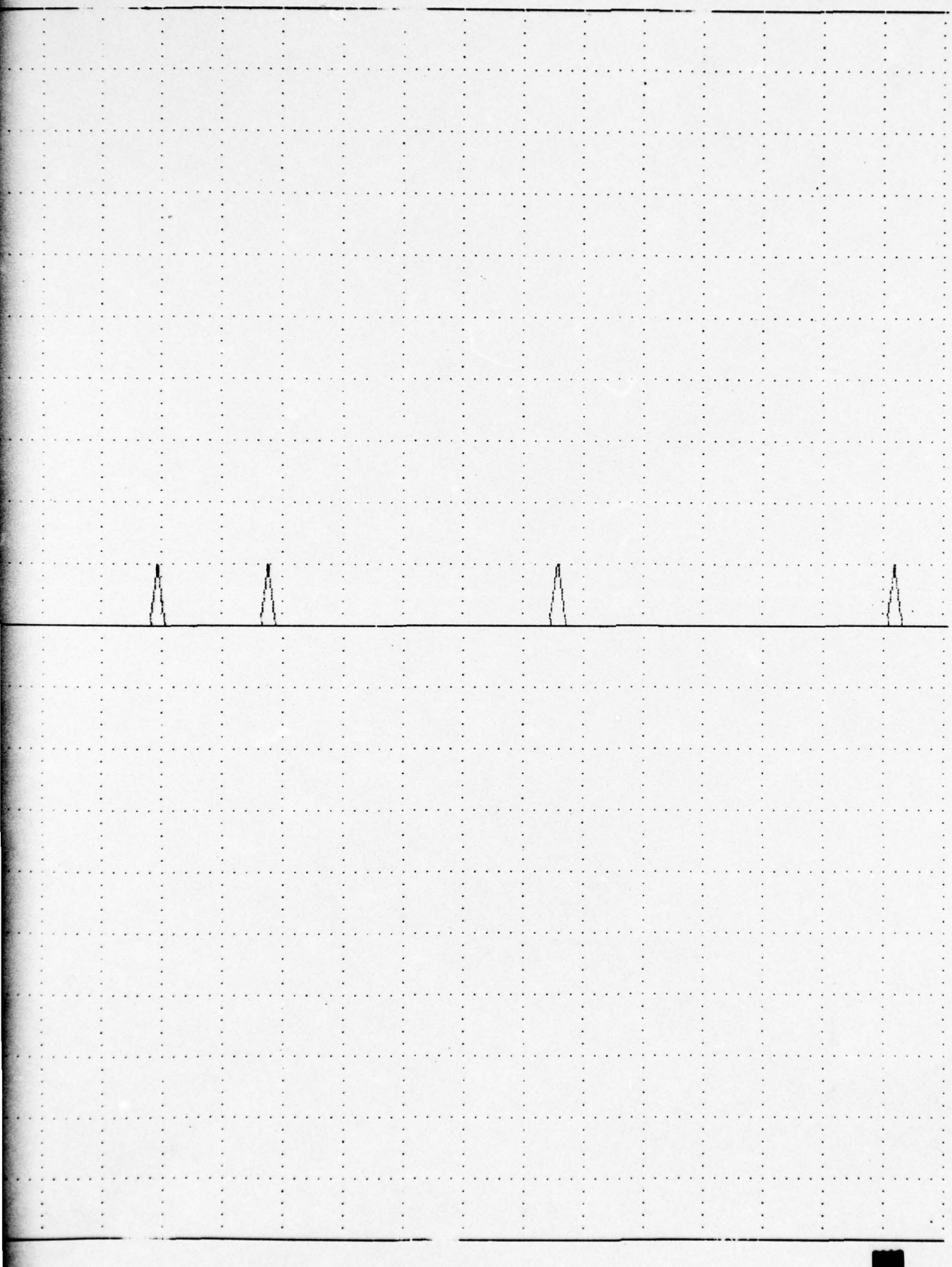
AMPLE PERIOD



4 FT/SEC/PULSE







5

RECORD 1, FILE 2

SOLID LINE = VARIABLE 2, BIAS = -12.00000, OPERATION = VARIABLE 0, VERTICAL SCALE (PER INCH) = 2.00000
DOTTED LINE = VARIABLE 31, BIAS = 0.00000, OPERATION = VARIABLE 0, VERTICAL SCALE (PER INCH) = 1.00000
DASHED LINE = VARIABLE 31, BIAS = 0.00000, OPERATION = VARIABLE 0, VERTICAL SCALE (PER INCH) = 1.00000
START TIME = 0.00 STOP TIME = 4.00 HORIZONTAL SCALE (PER INCH) = 0.06

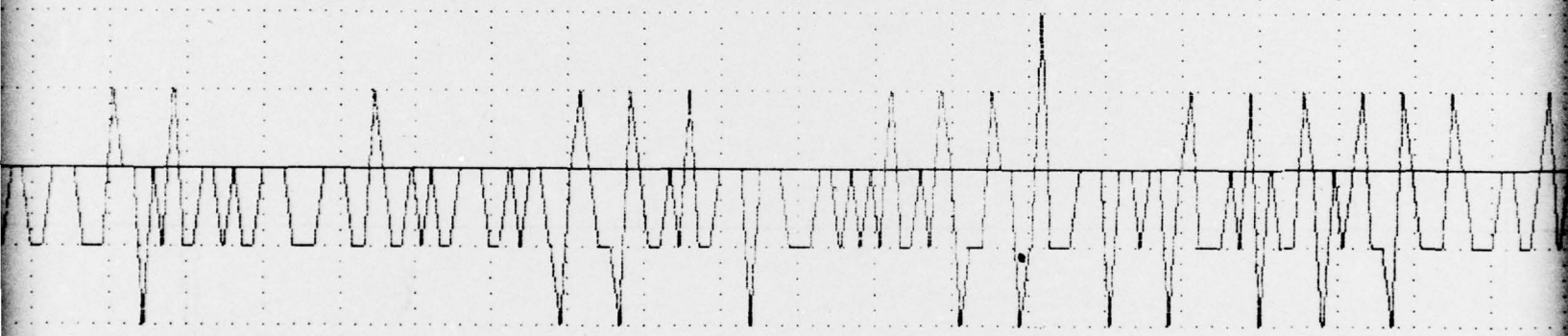
← NET COUNT EACH 256 Hz SAMPLE PERIO

8
10
12
14
16

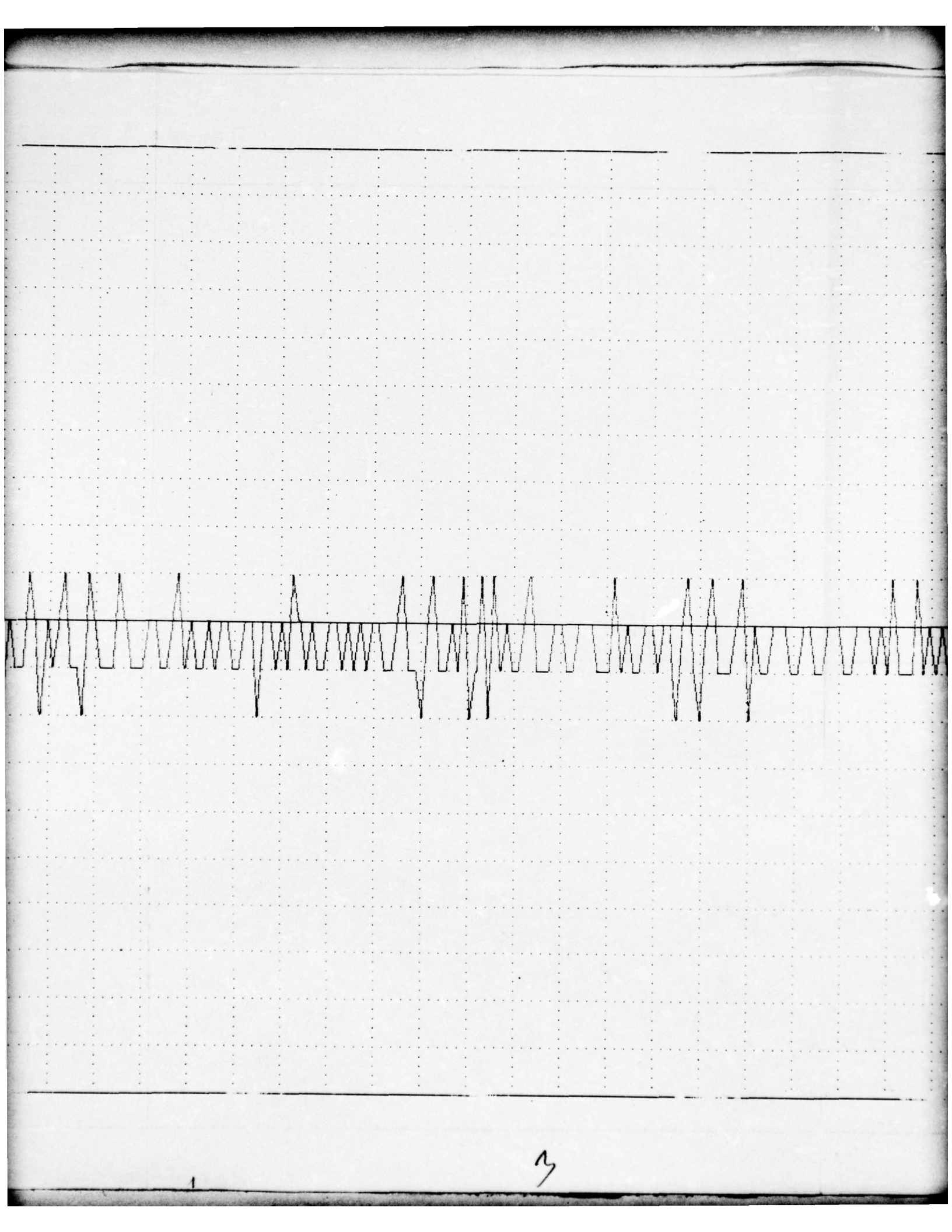
11/20/75
HYPHA INTERPOLATOR
T_c = 262,144 Hz
PULSE WEIGHT = .001224 FT/SEC/PUL

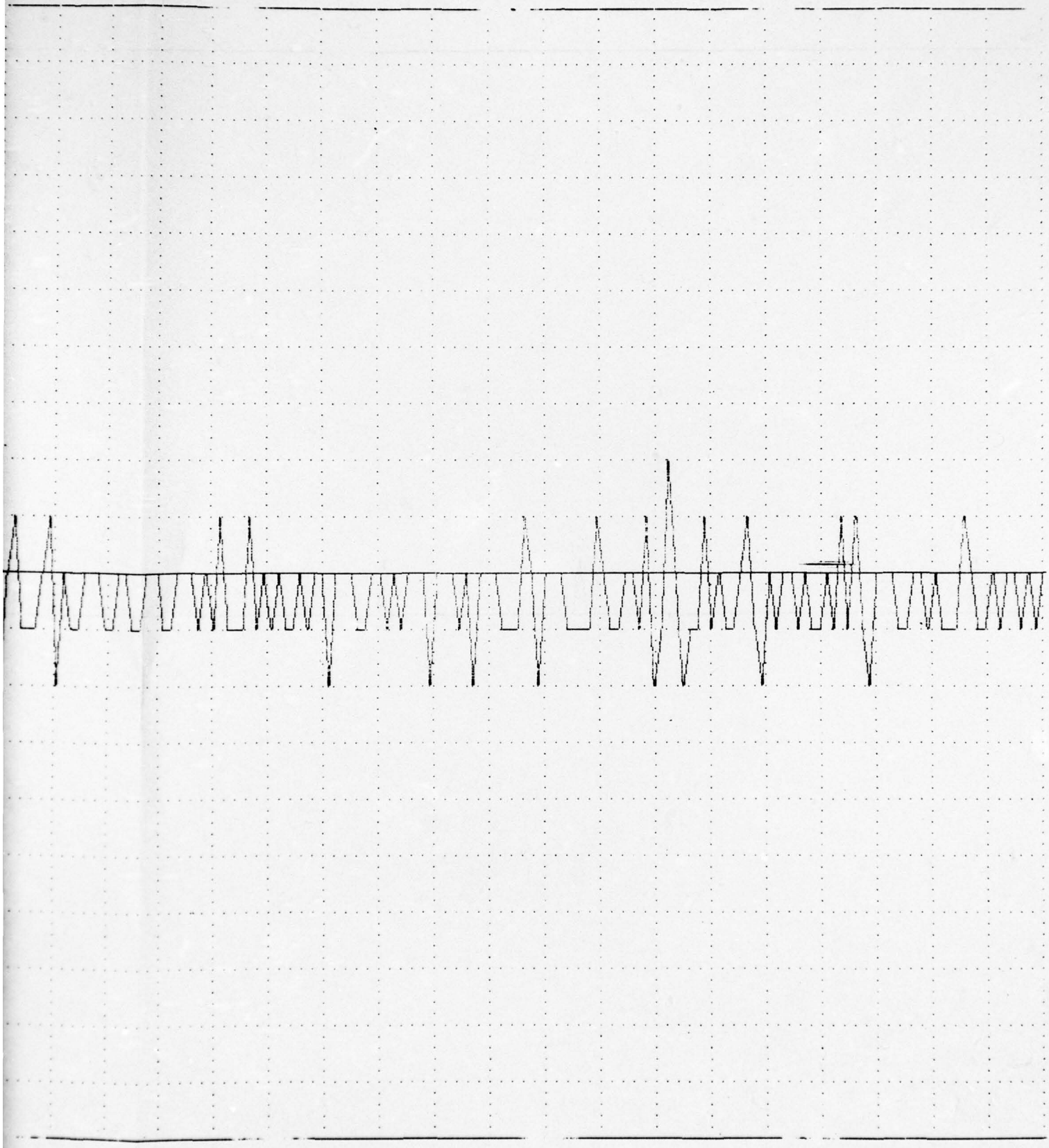
TIME: SECONDS

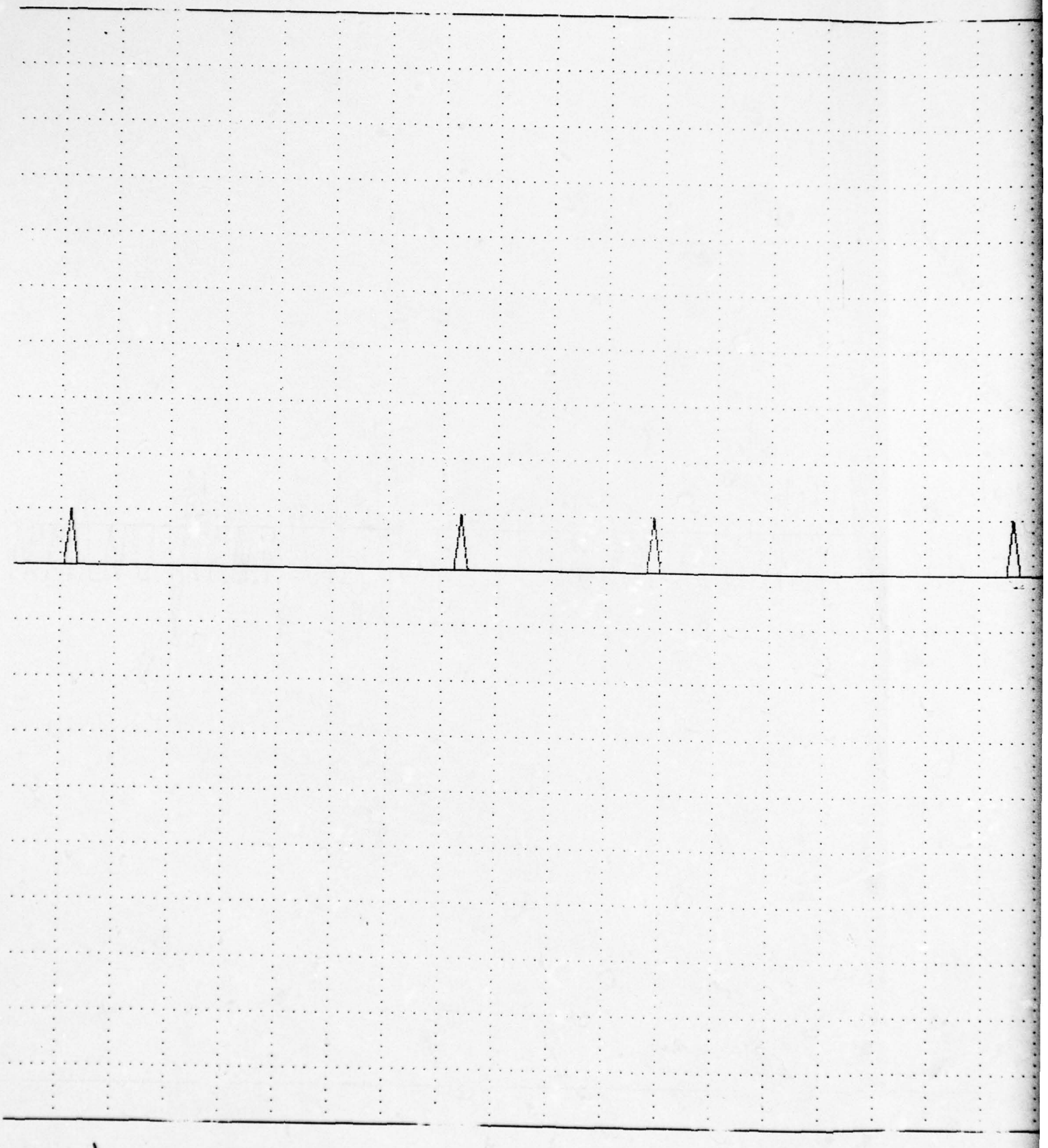
SAMPLE PERIOD

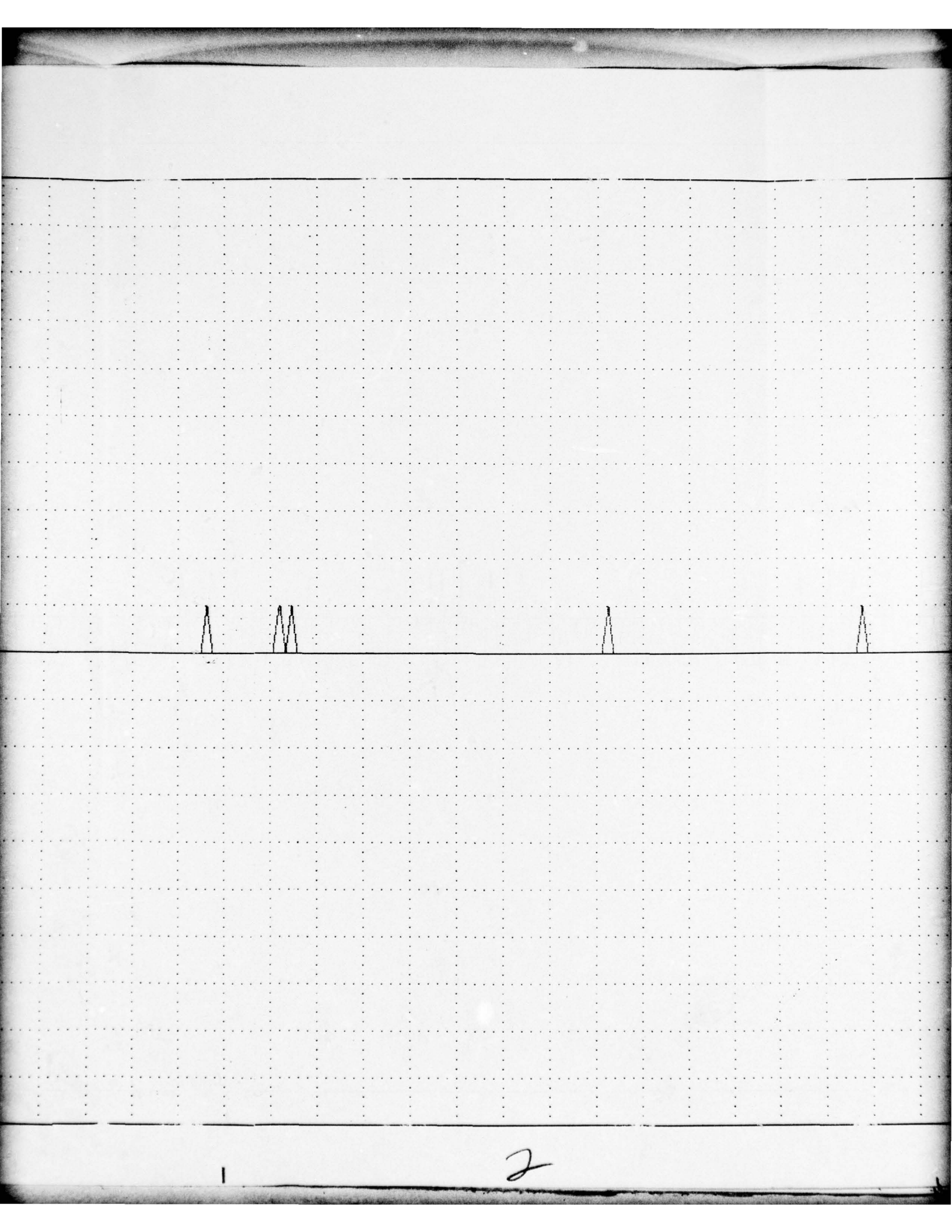


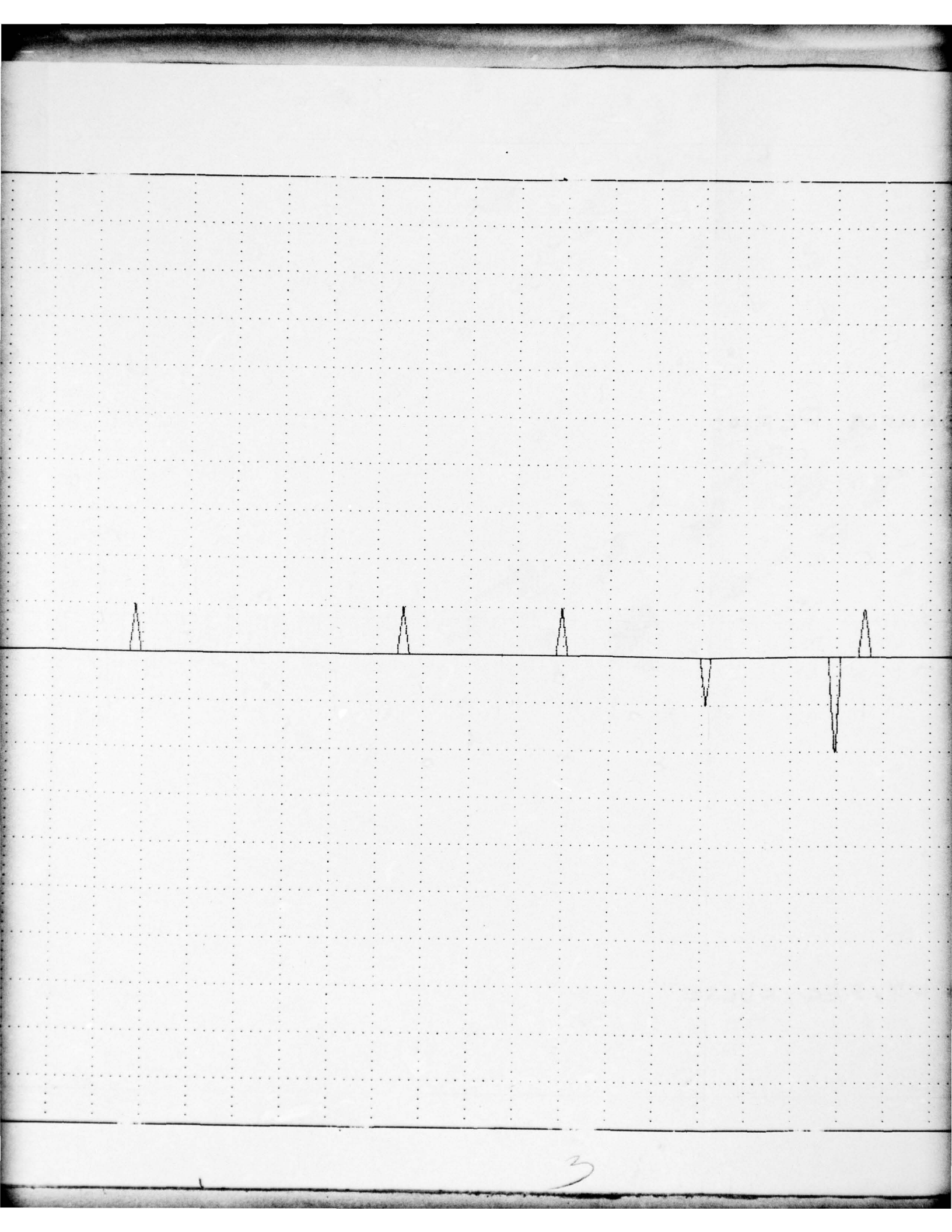
FT/SEC/PULSE








1
2



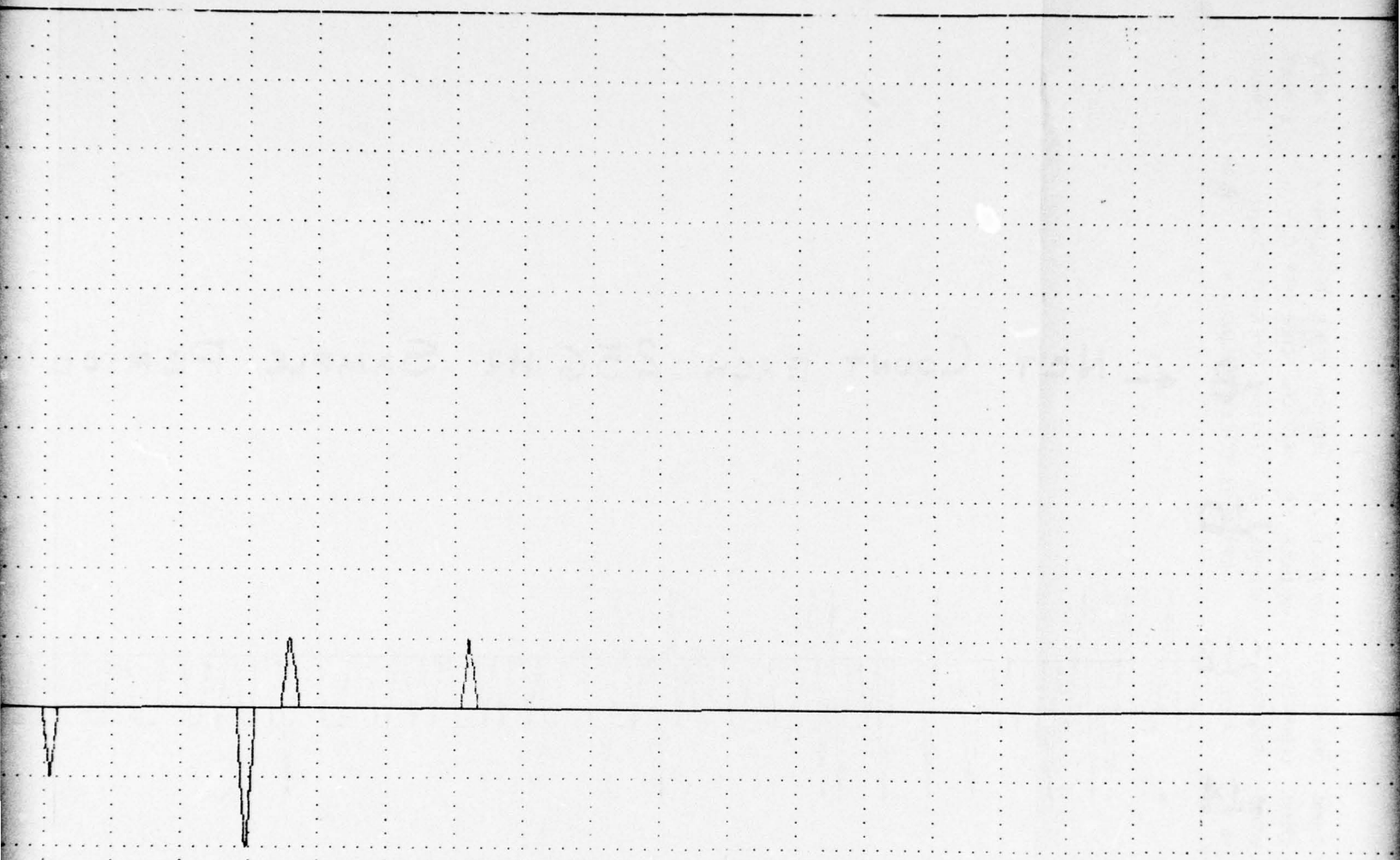


FIGURE 4.2-38. PLOT OF LONG
STABILITY

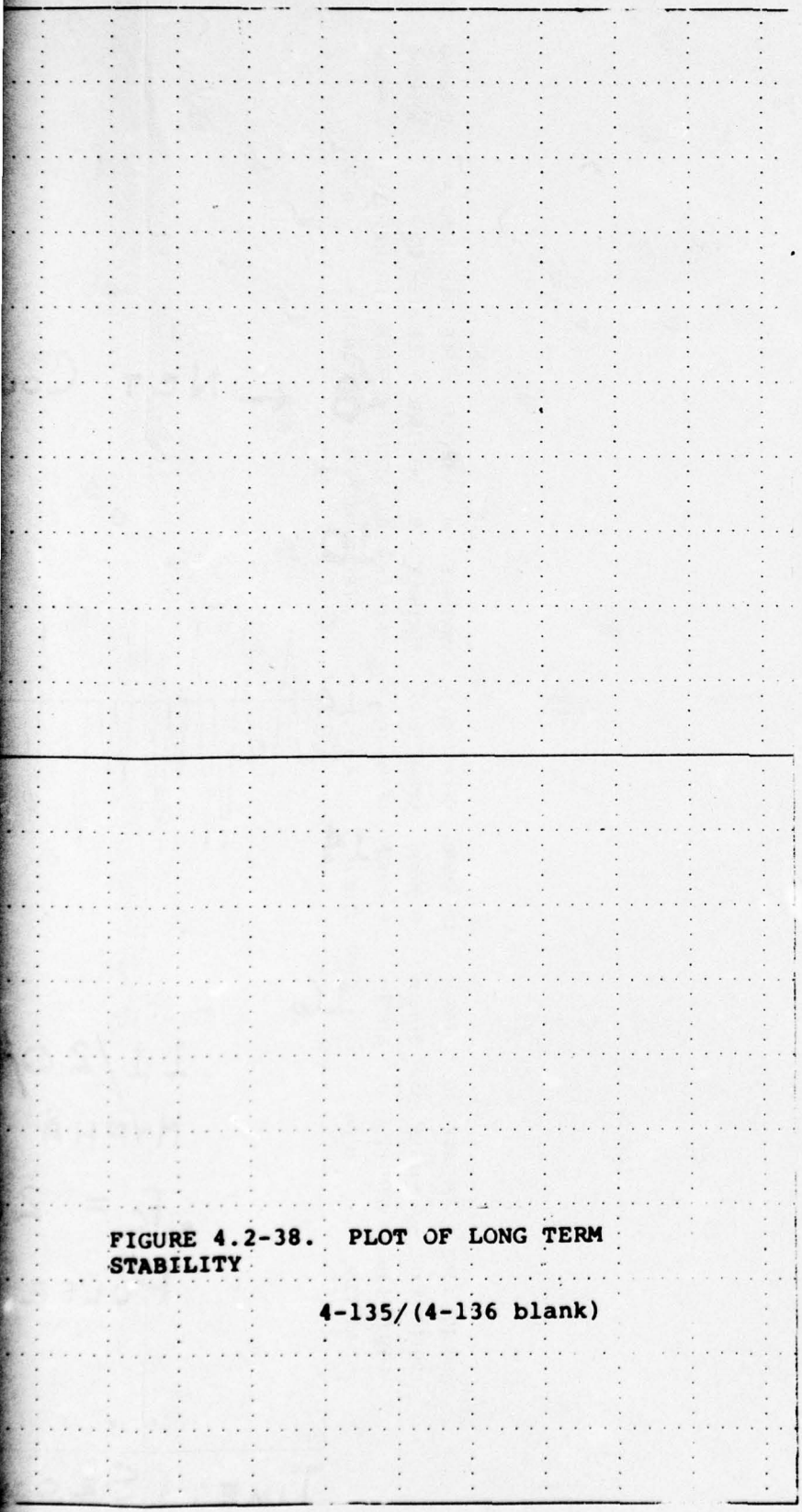
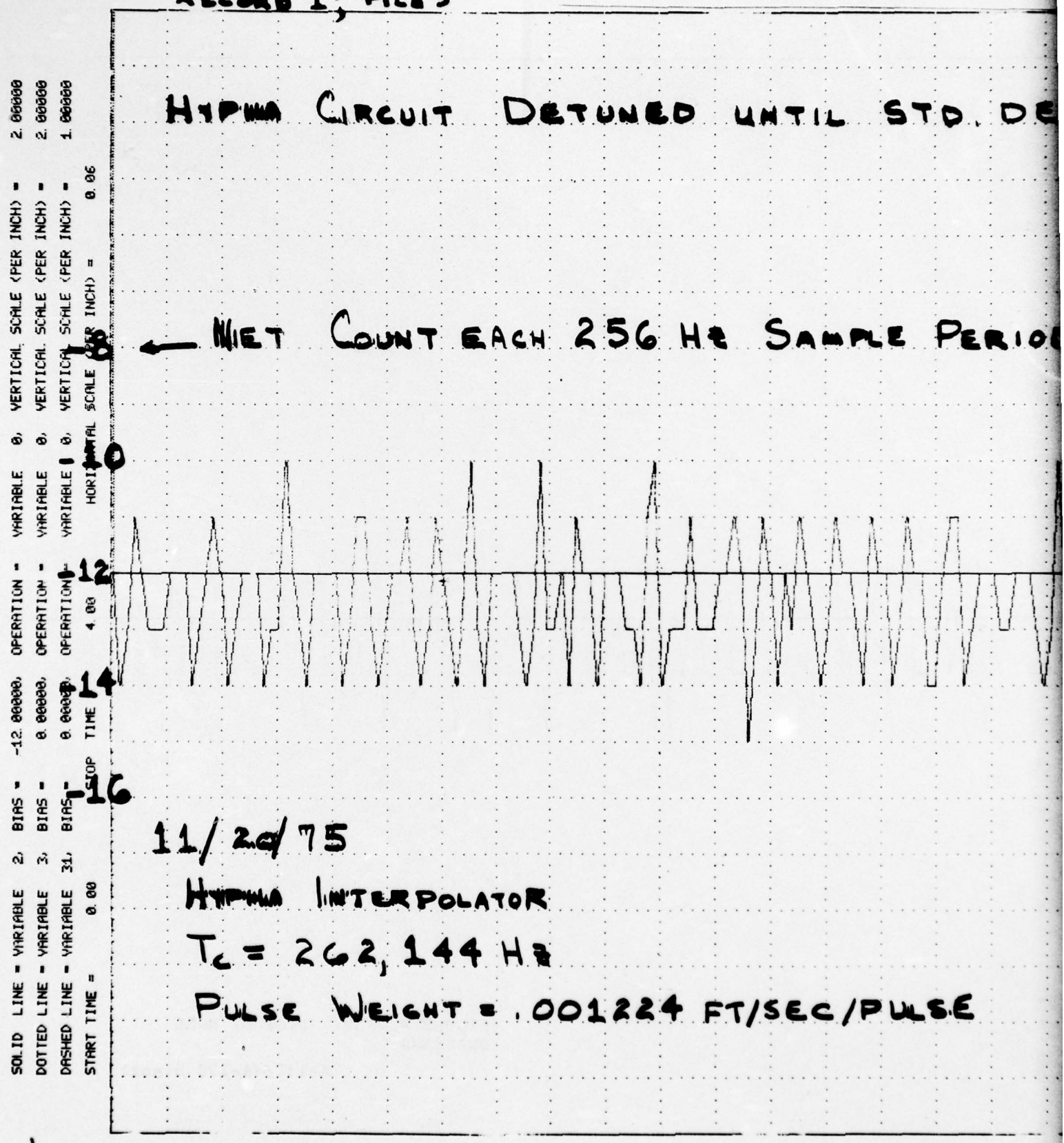


FIGURE 4.2-38. PLOT OF LONG TERM STABILITY

RECORD 1; FILE 3



11/20/75

HYPHA INTERPOLATOR

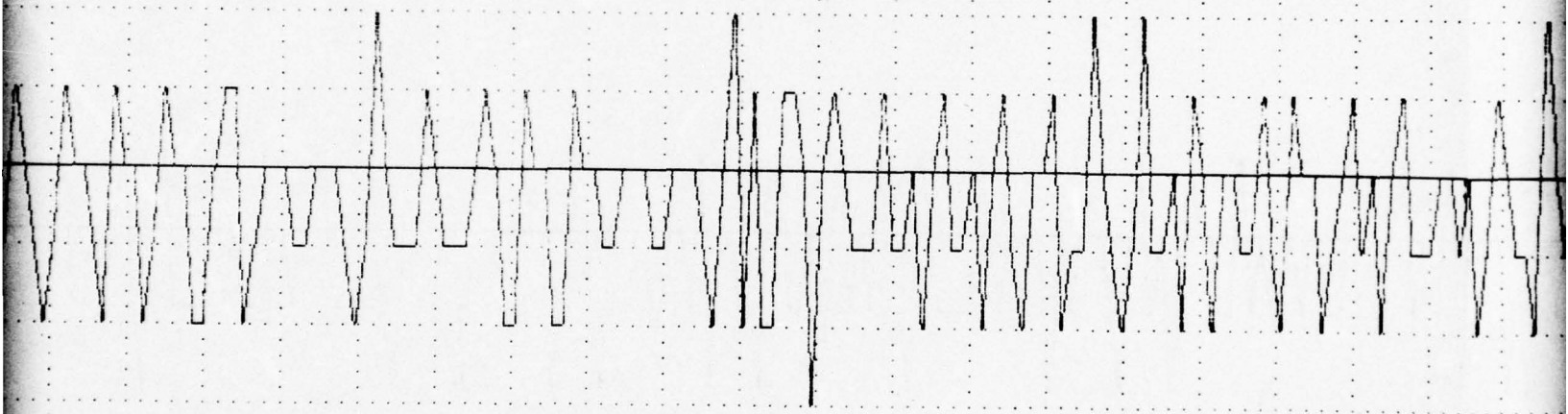
T_c = 262,144 Hz

PULSE WEIGHT = .001224 FT/SEC/PULSE

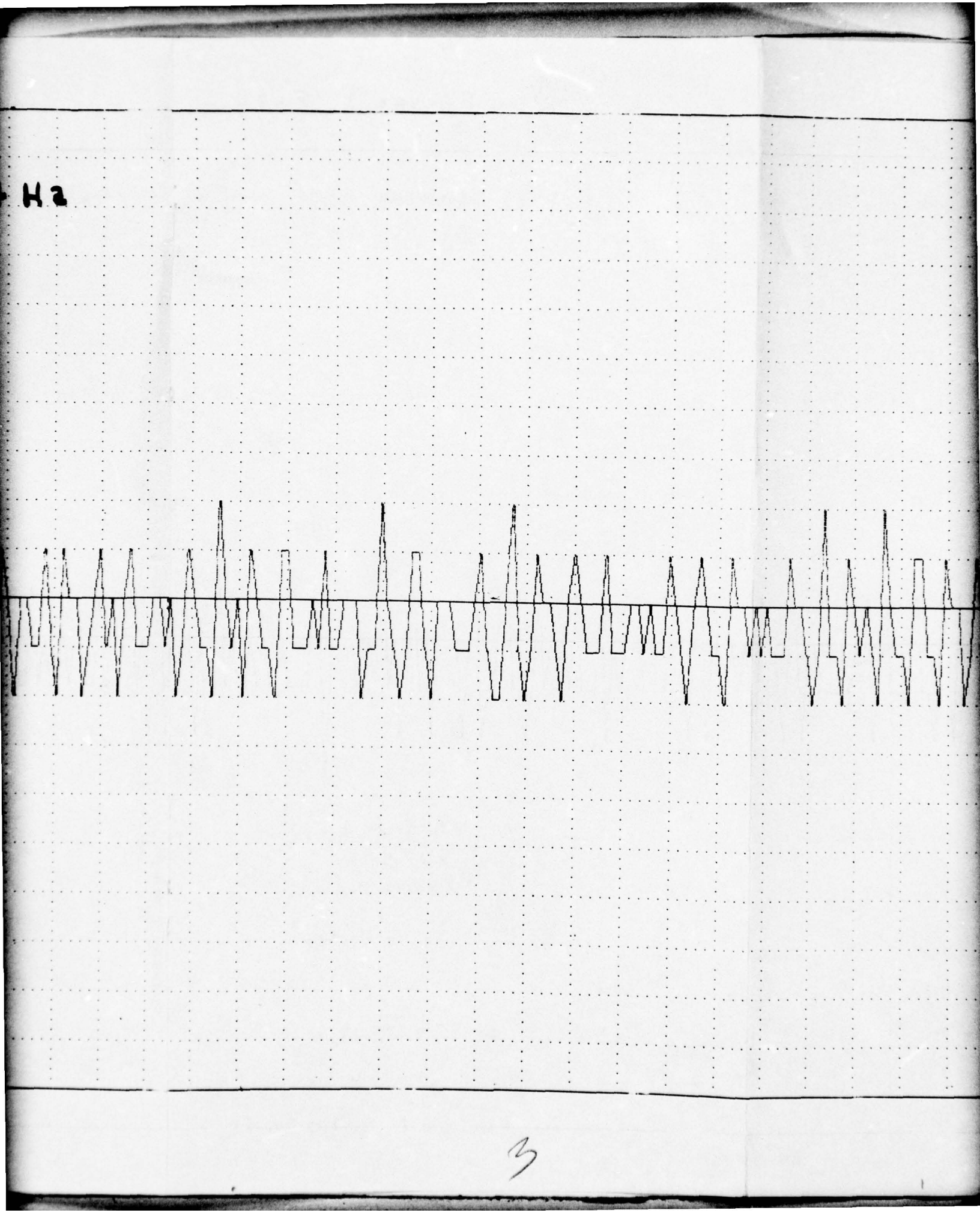
TIME: SECONDS

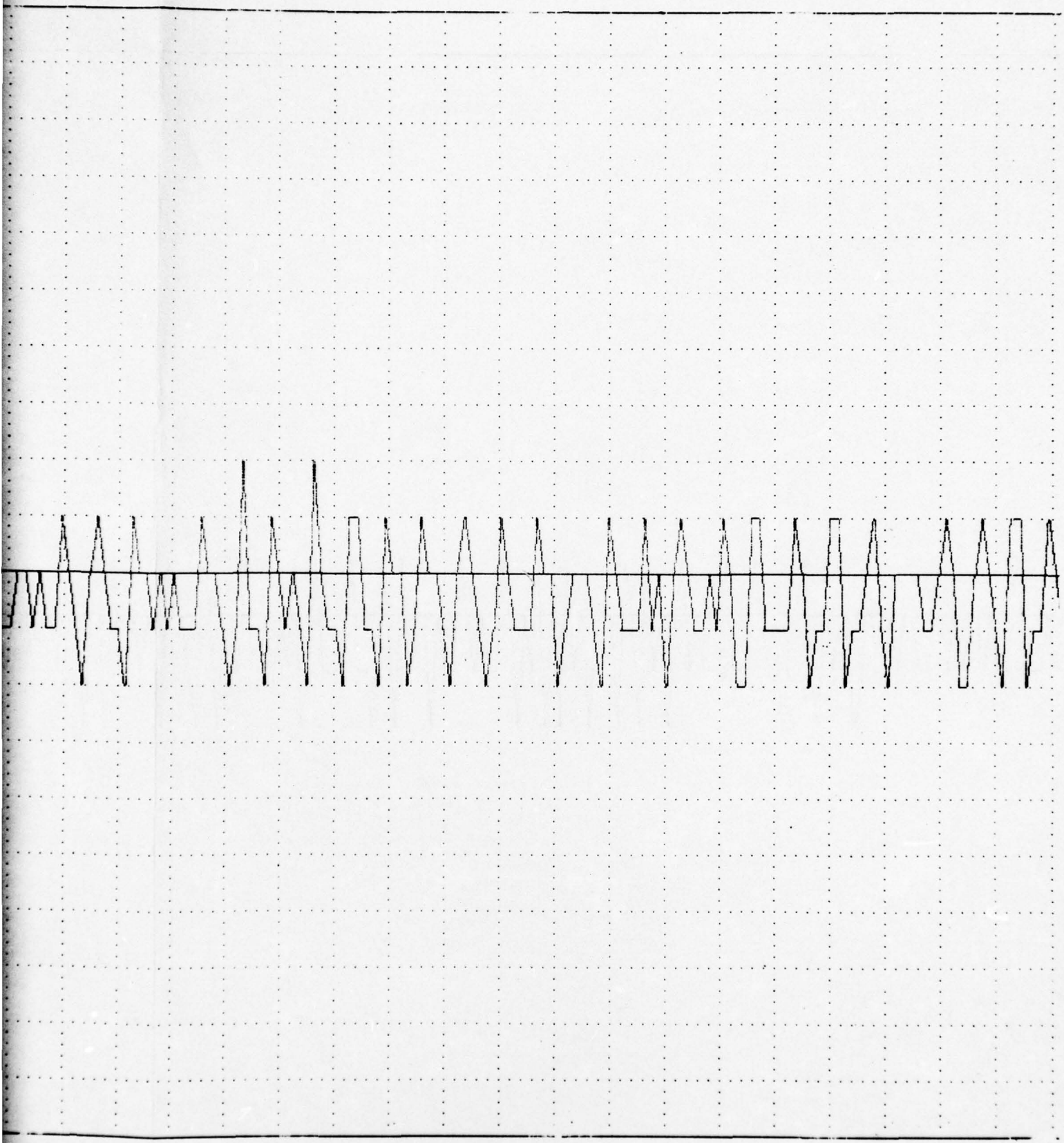
TIL STD. DEV = 1.0 PULSE AT 262,144 Hz

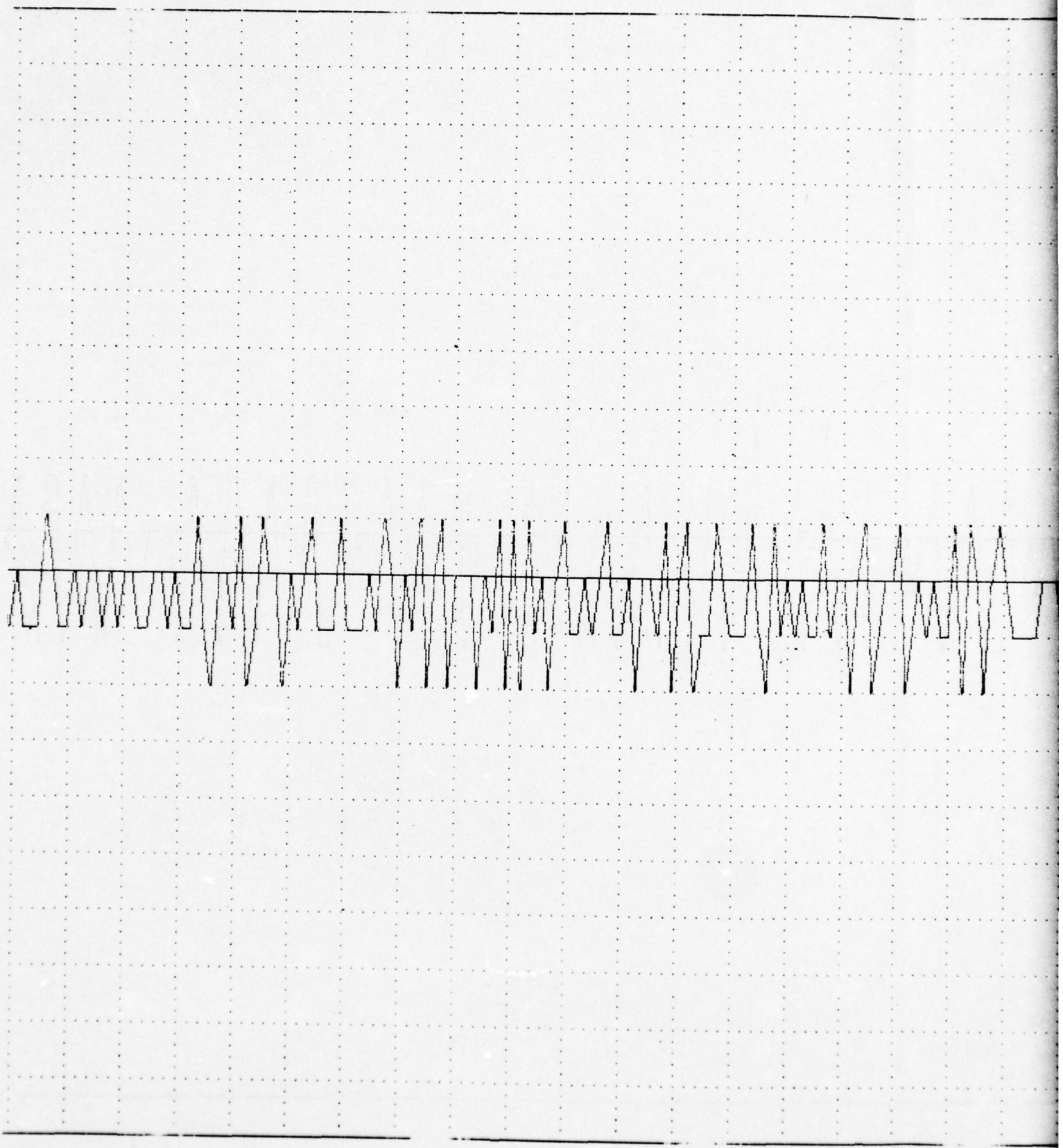
AMPLE PERIOD

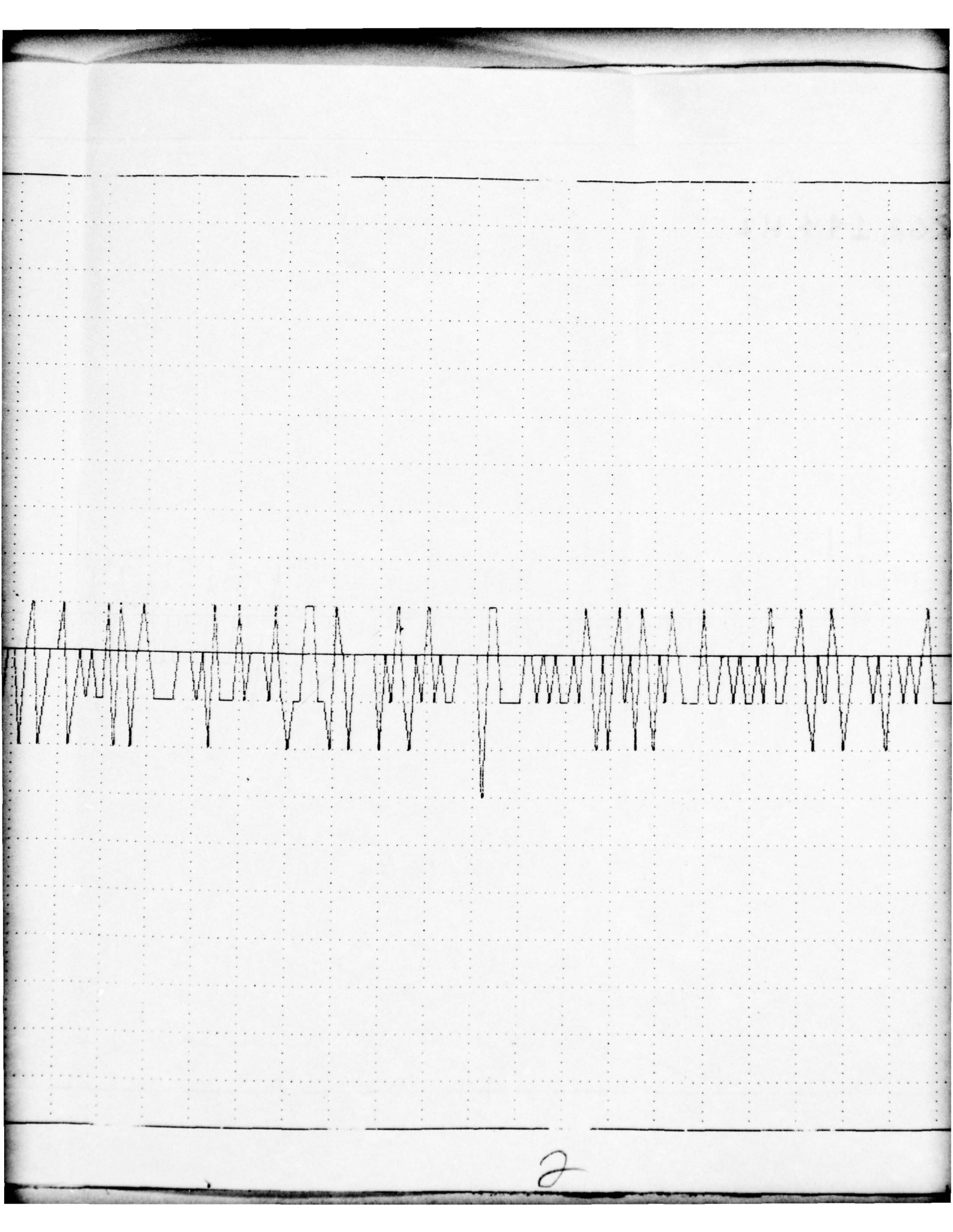


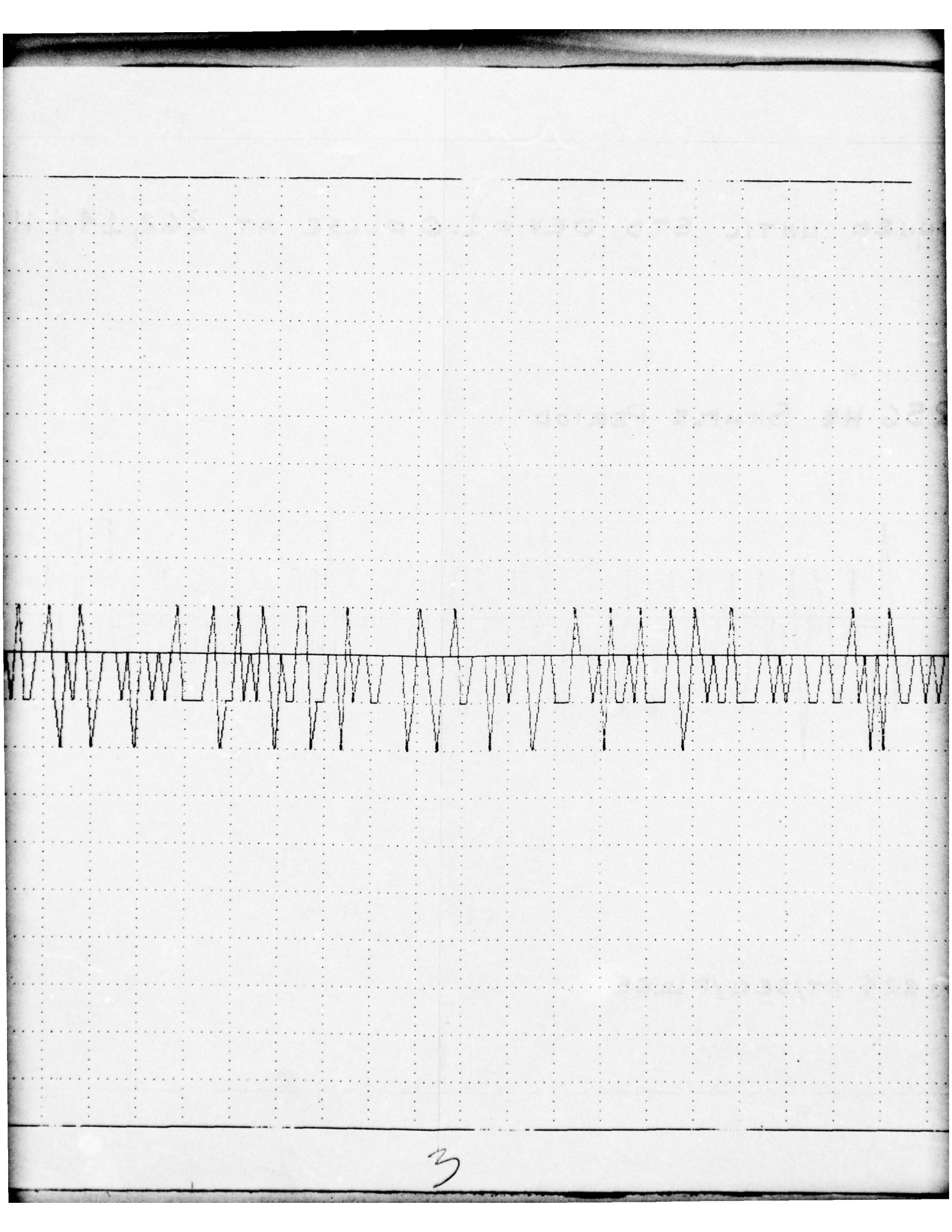
C/PULSE


Ha









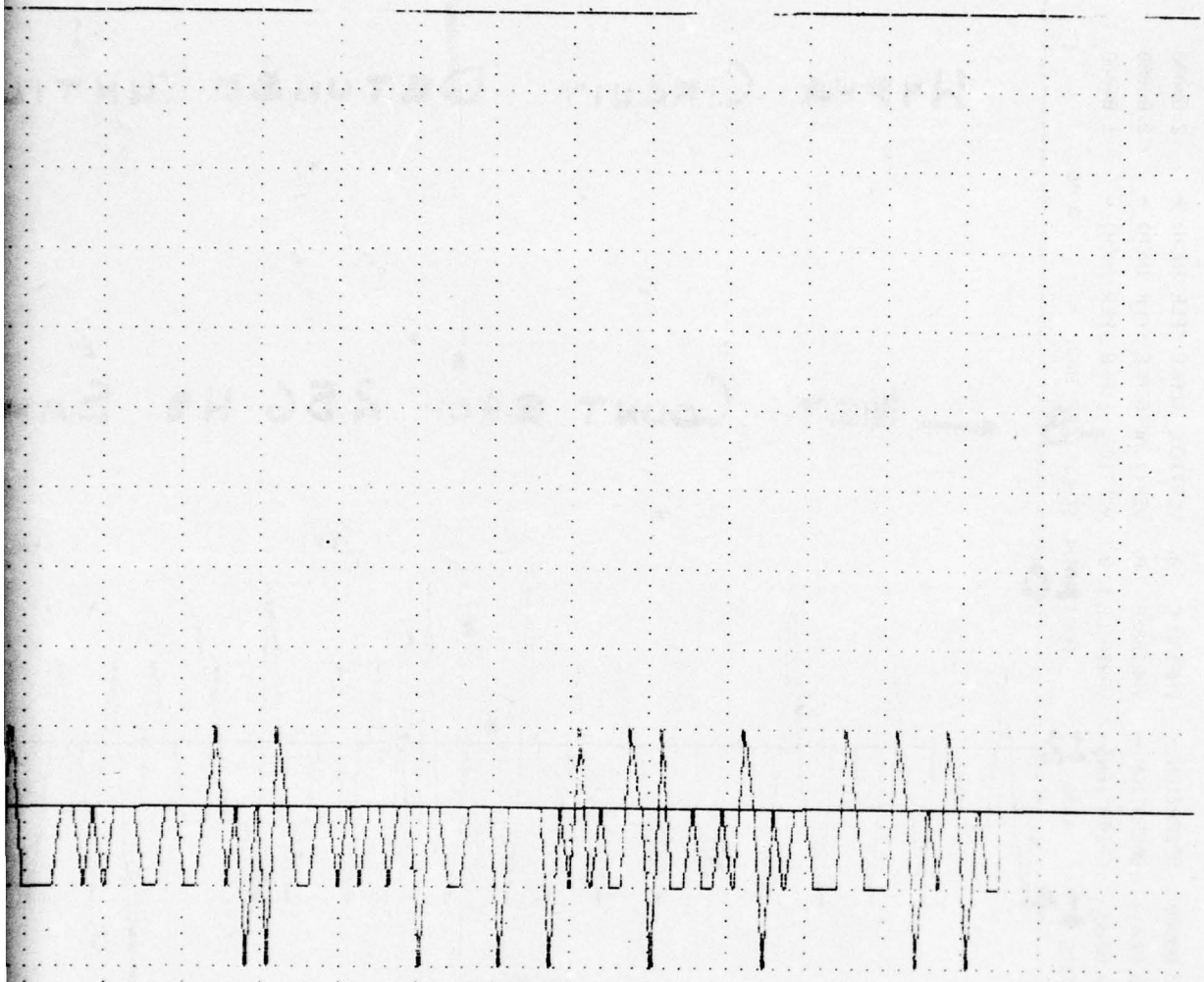
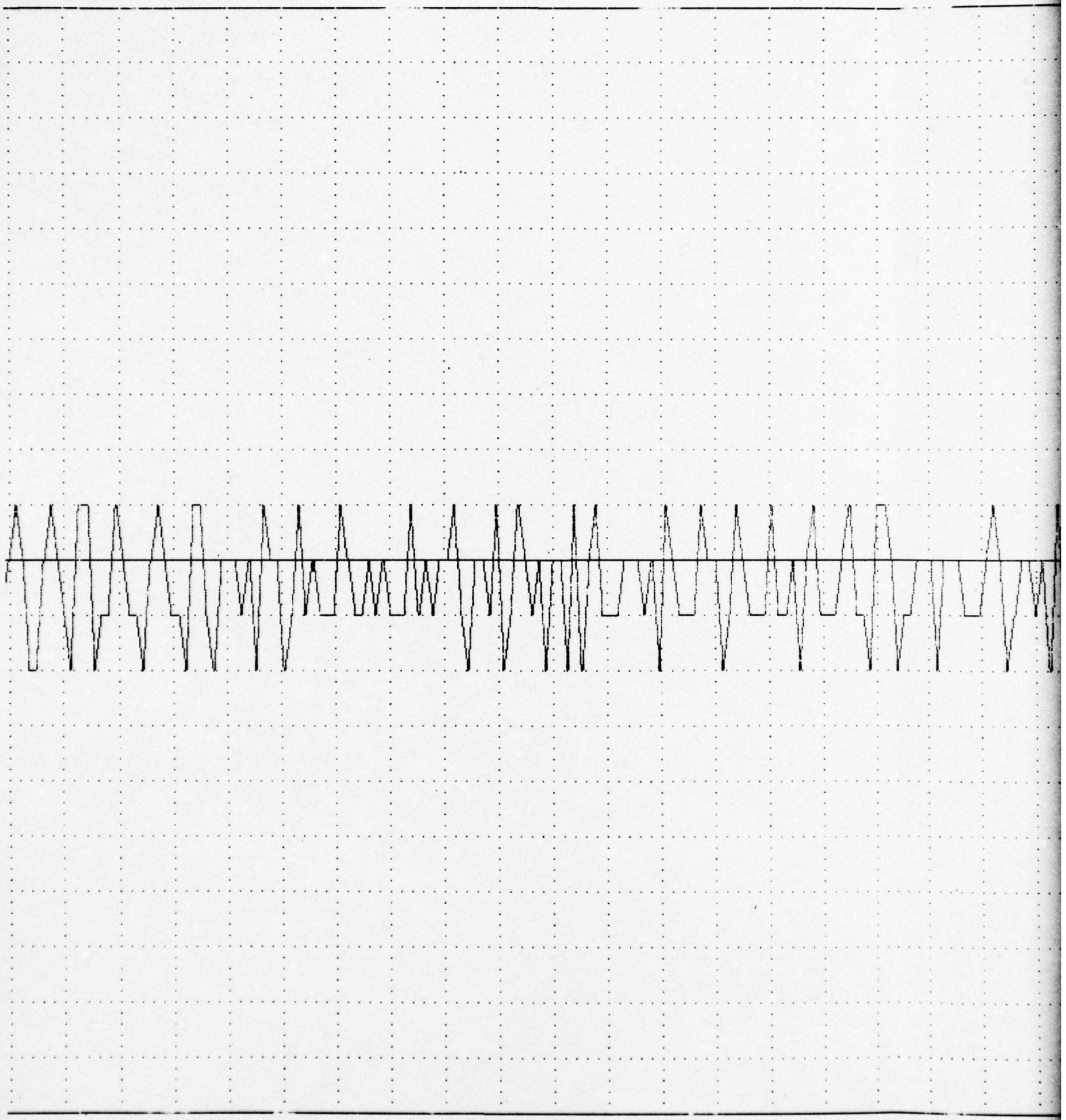
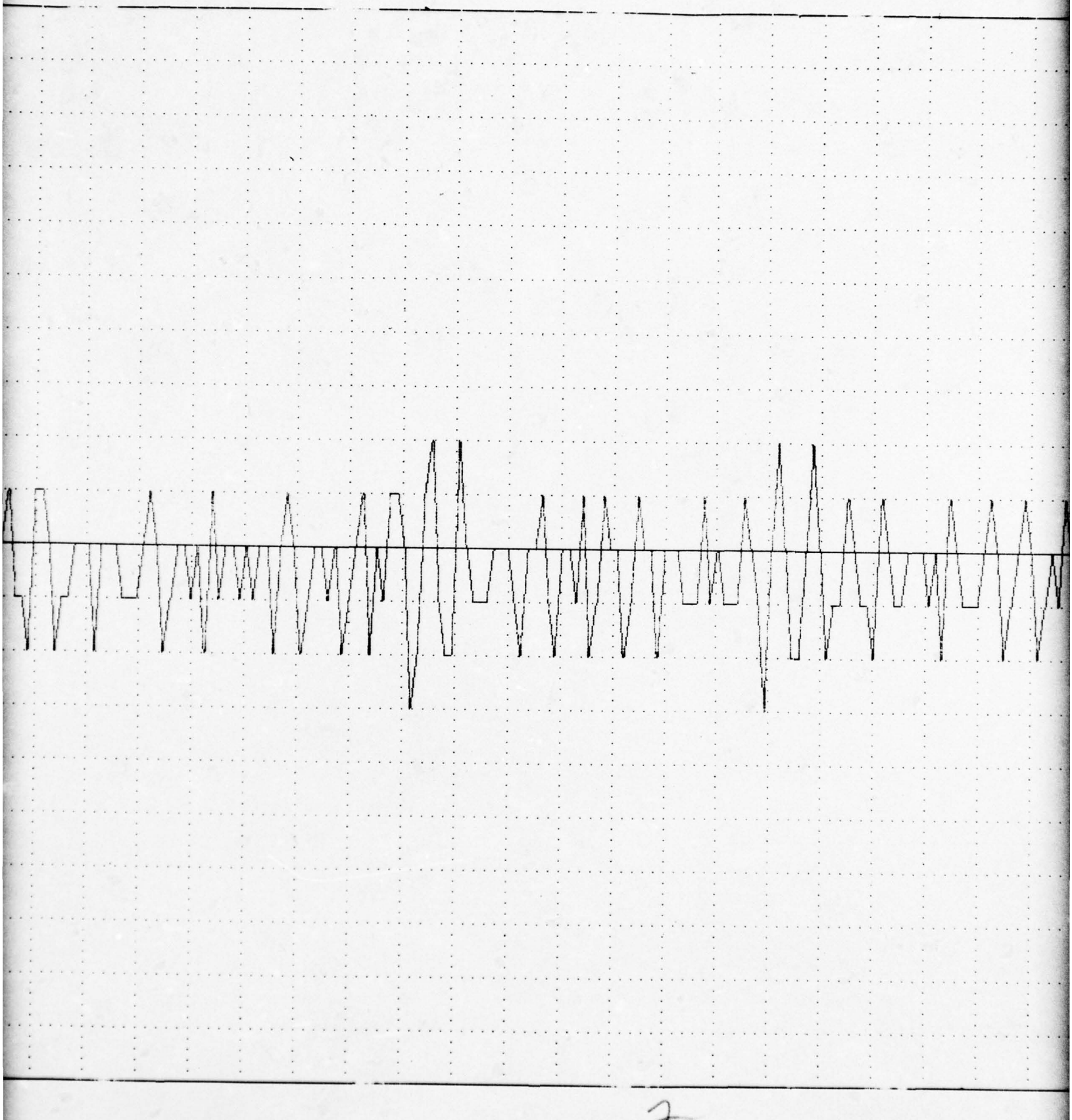


FIGURE 4.2-39. PLOT OF NULL DEADBAND





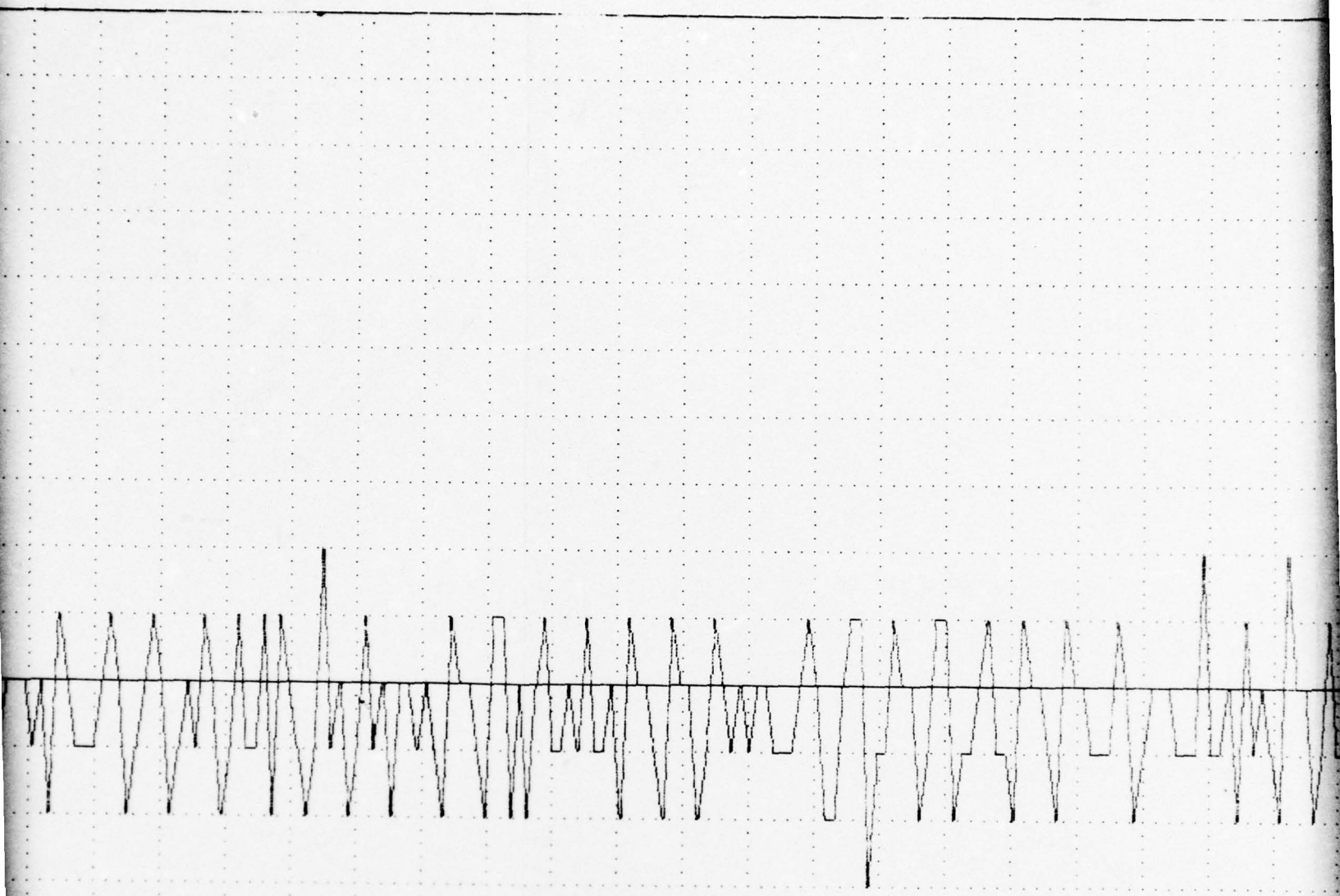


FIGURE 4.2-
TEST DATA

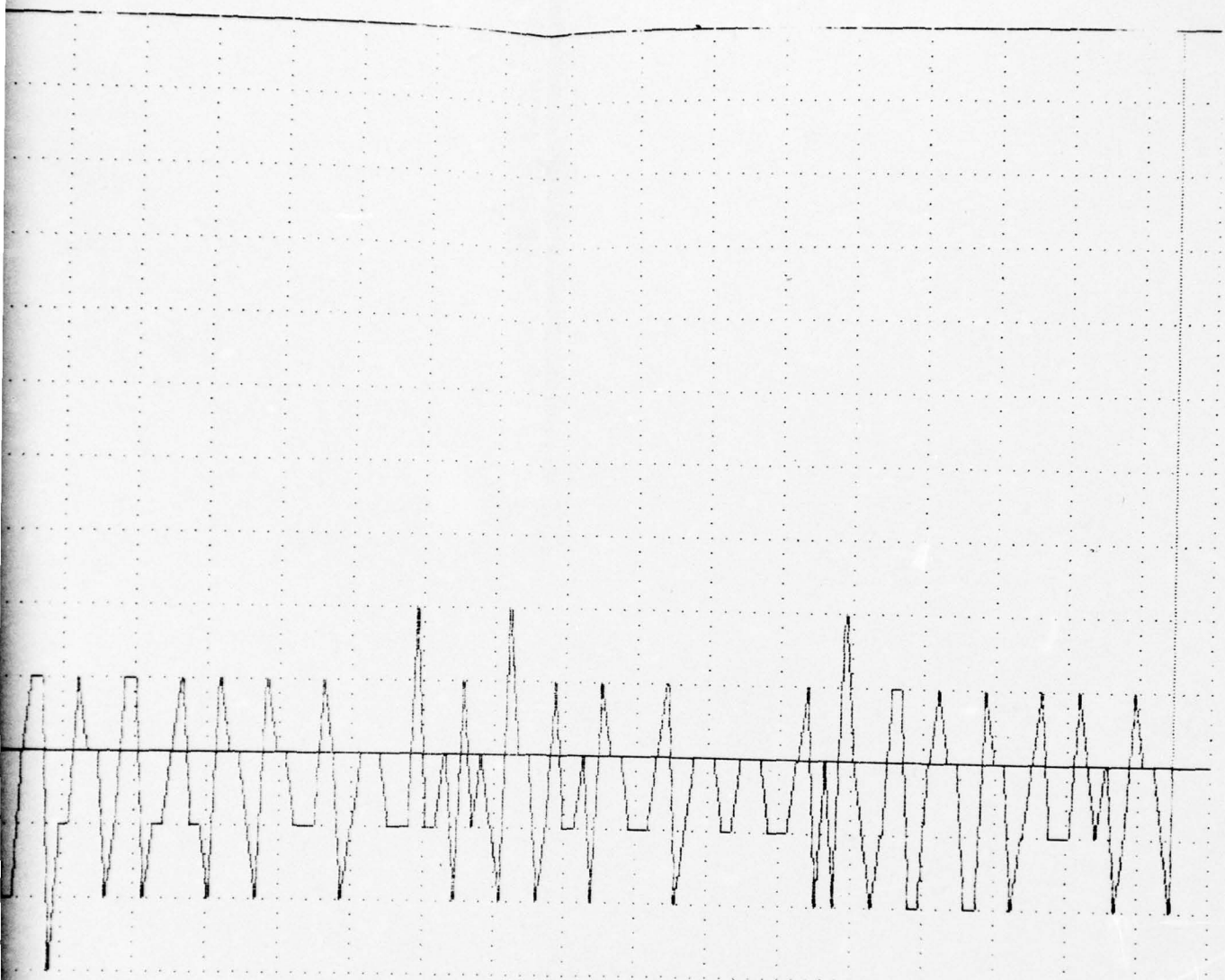


FIGURE 4.2-40. PLOT OF LINEARITY TEST DATA

TABLE 4.2-4. ACCELEROMETER LOOP LINEARITY
HYPHA INTERPOLATOR

Parameter	Micro-g
Peak Deviation From a Line	-52
Mean Deviation From the Mean Deviation From a Line	-22.8
RMS Deviation From the Mean Deviation From a Line	15.9
1g bias	-526
0g bias	-578
(1g-0g) bias	-52

TABLE 4.2-5. ACCELEROMETER LOOP PERFORMANCE
HYPHA INTERPOLATOR

Parameter	Cond	Value
Velocity Noise	Min	0.2
	Max	0.96
	Avg	0.5
1g Bias Stability (μg) RMS	CD	20.5
	NCD	10.1
1g Scale Factor Stability (ppm) RMS	CD	13.3
	NCD	7.9
Linearity: Standard Deviation (μg) From a Line		-22.8
Threshold Arc-Second	Max	<0.5

TABLE 4.2-6. VELOCITY NOISE SUMMARY
HYPHA INTERPOLATOR

(1/256 second net count summary over a 4 second period)

Input	Count Spread (pulses)	Std Dev (pulses)
0g	±4	0.3
0.12187g	+4, -6	0.911
1g	+4, -0	0.5

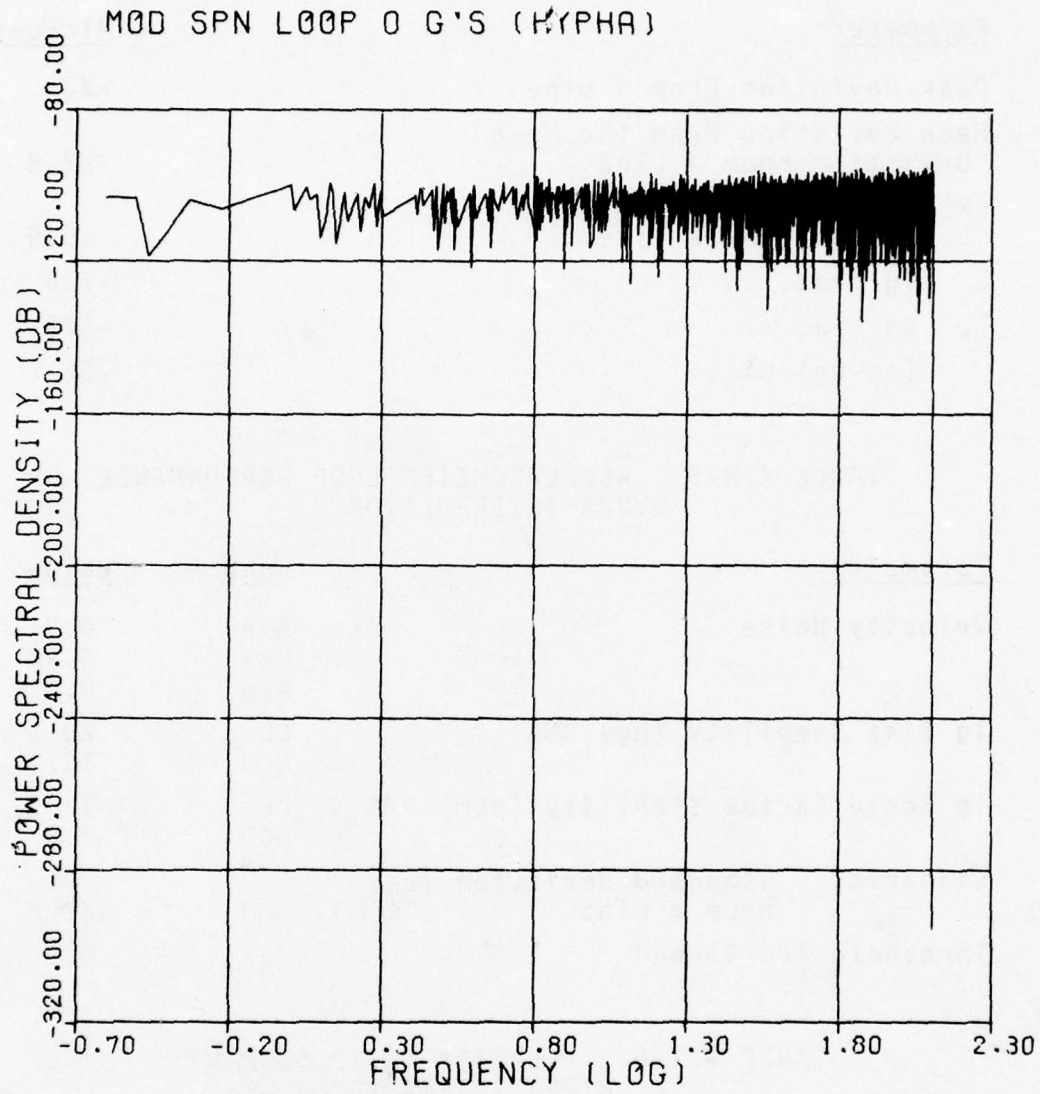


FIGURE 4.2-41. MOD SPN LOOP 0 g's (HYPHA)

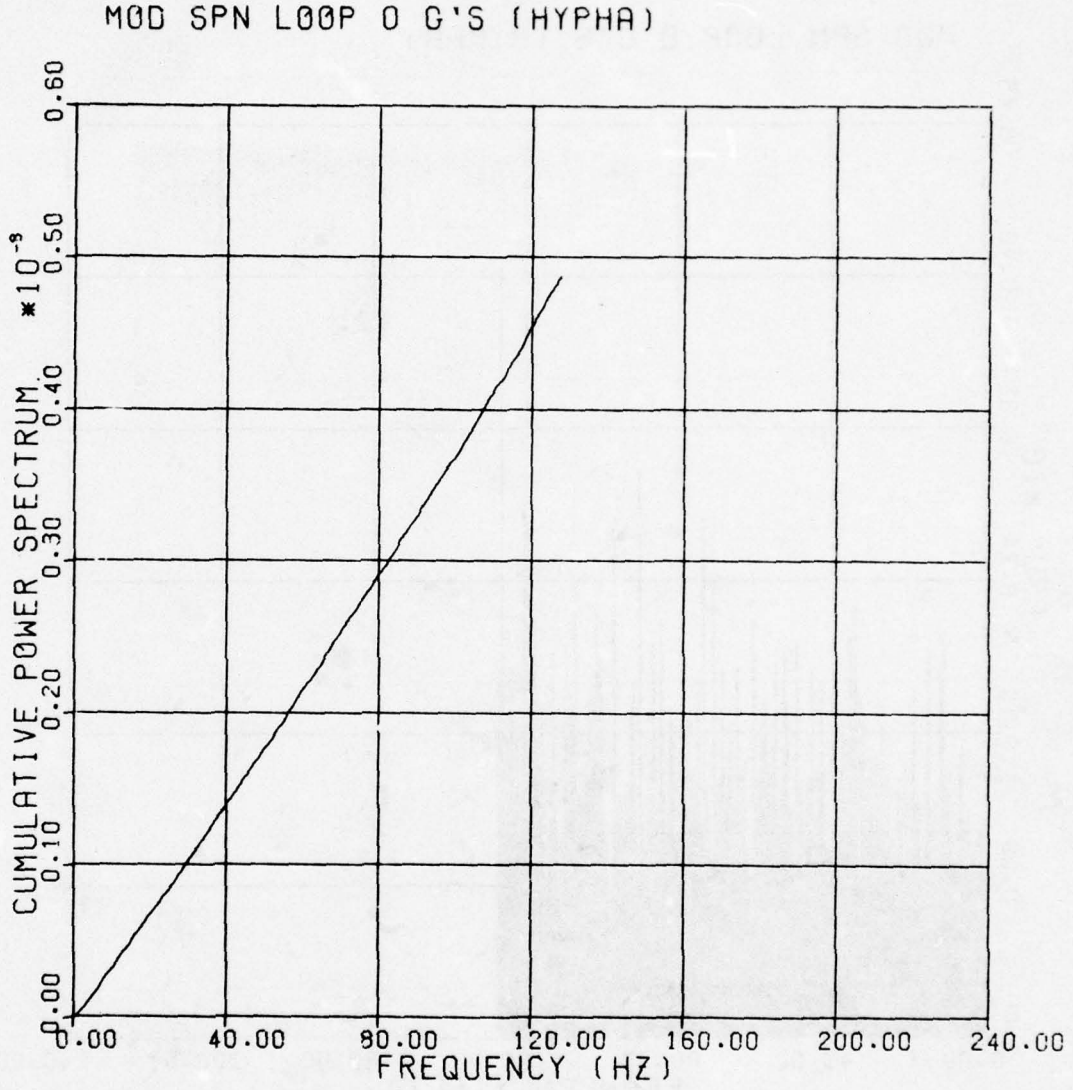


FIGURE 4.2-42. MOD SPN LOOP 0 g's (HYPHA)

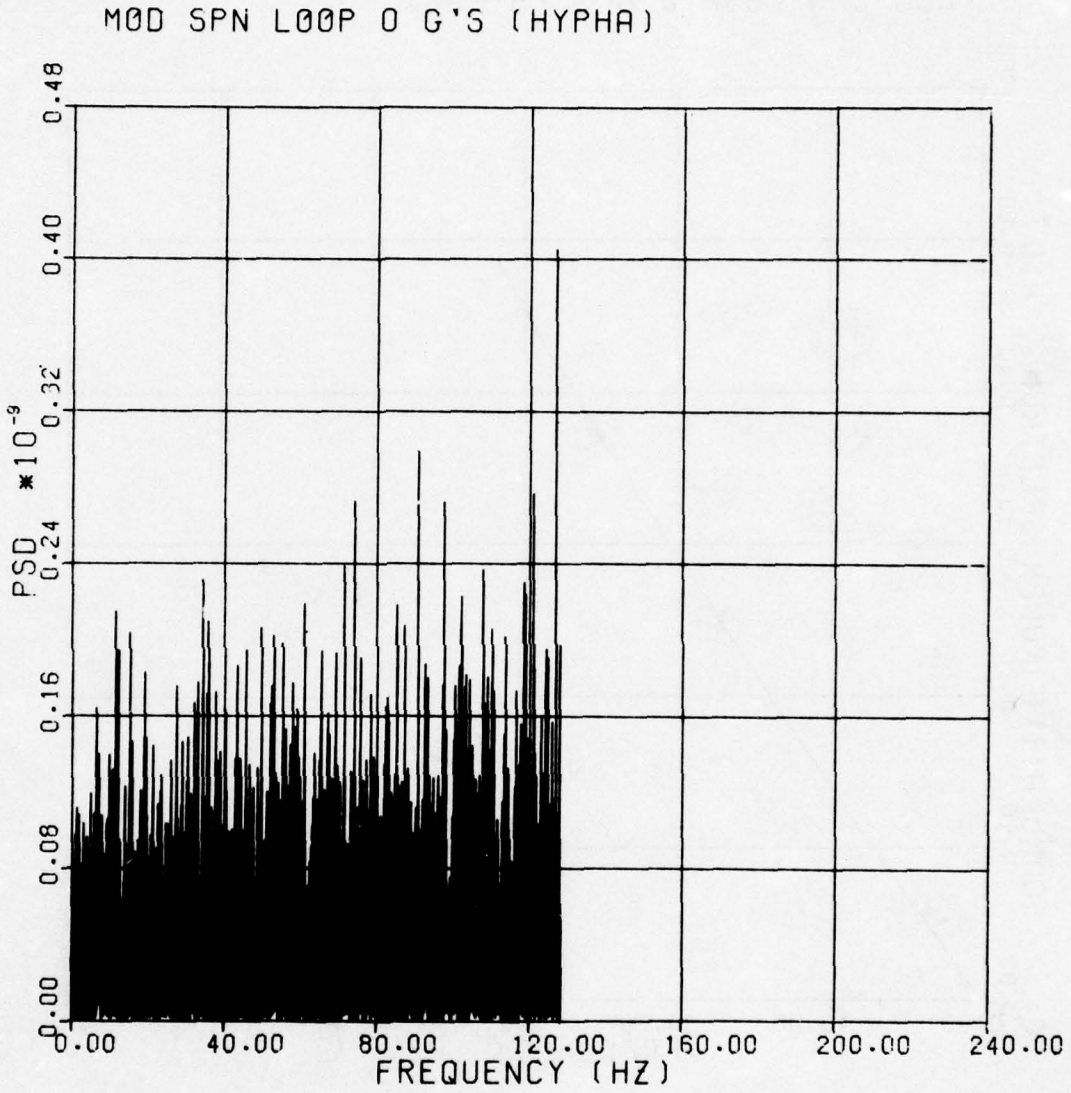


FIGURE 4.2-43. MOD SPN LOOP 0 g's (HYPHA)

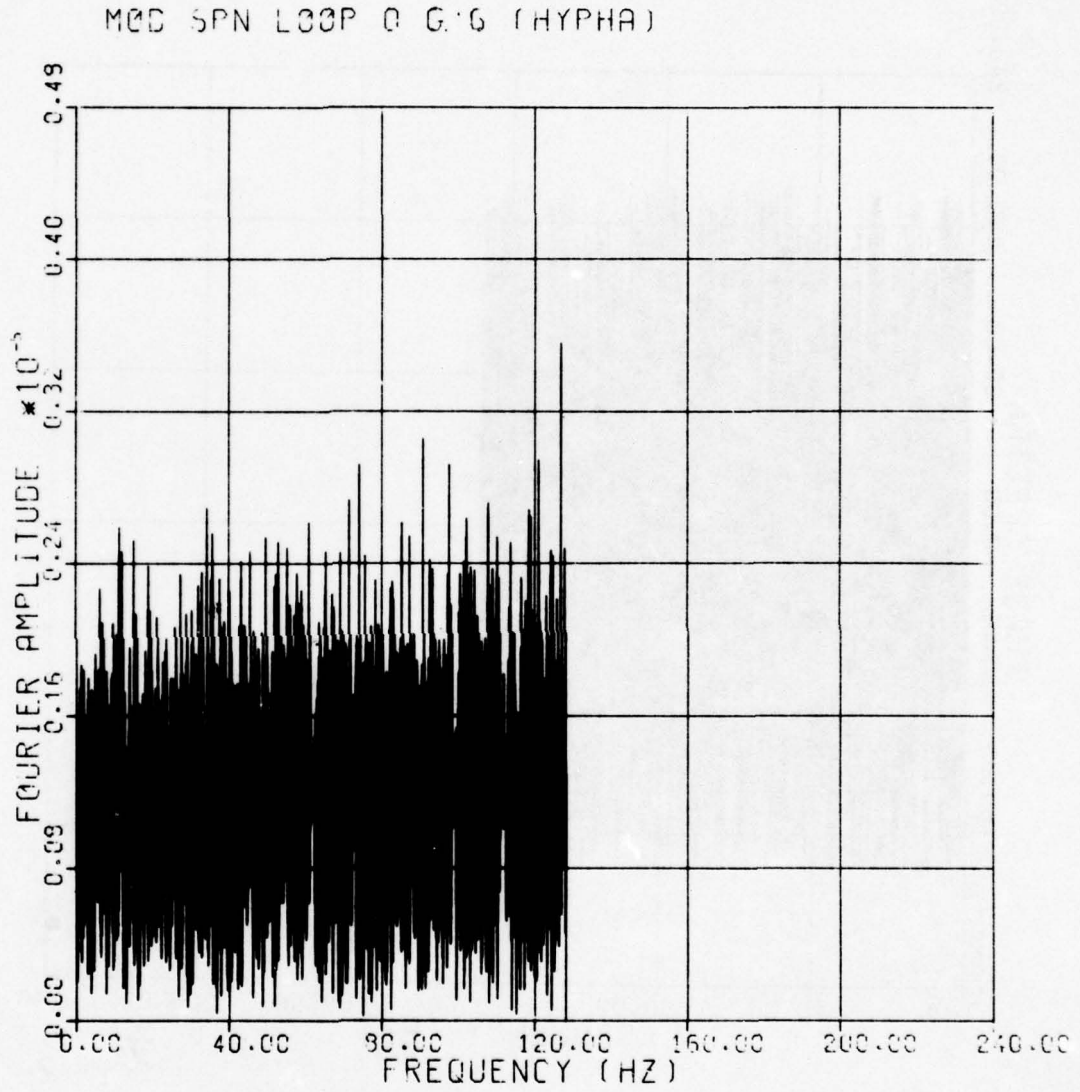


FIGURE 4.2-44. MOD SPN LOOP 0 g's (HYPHA)

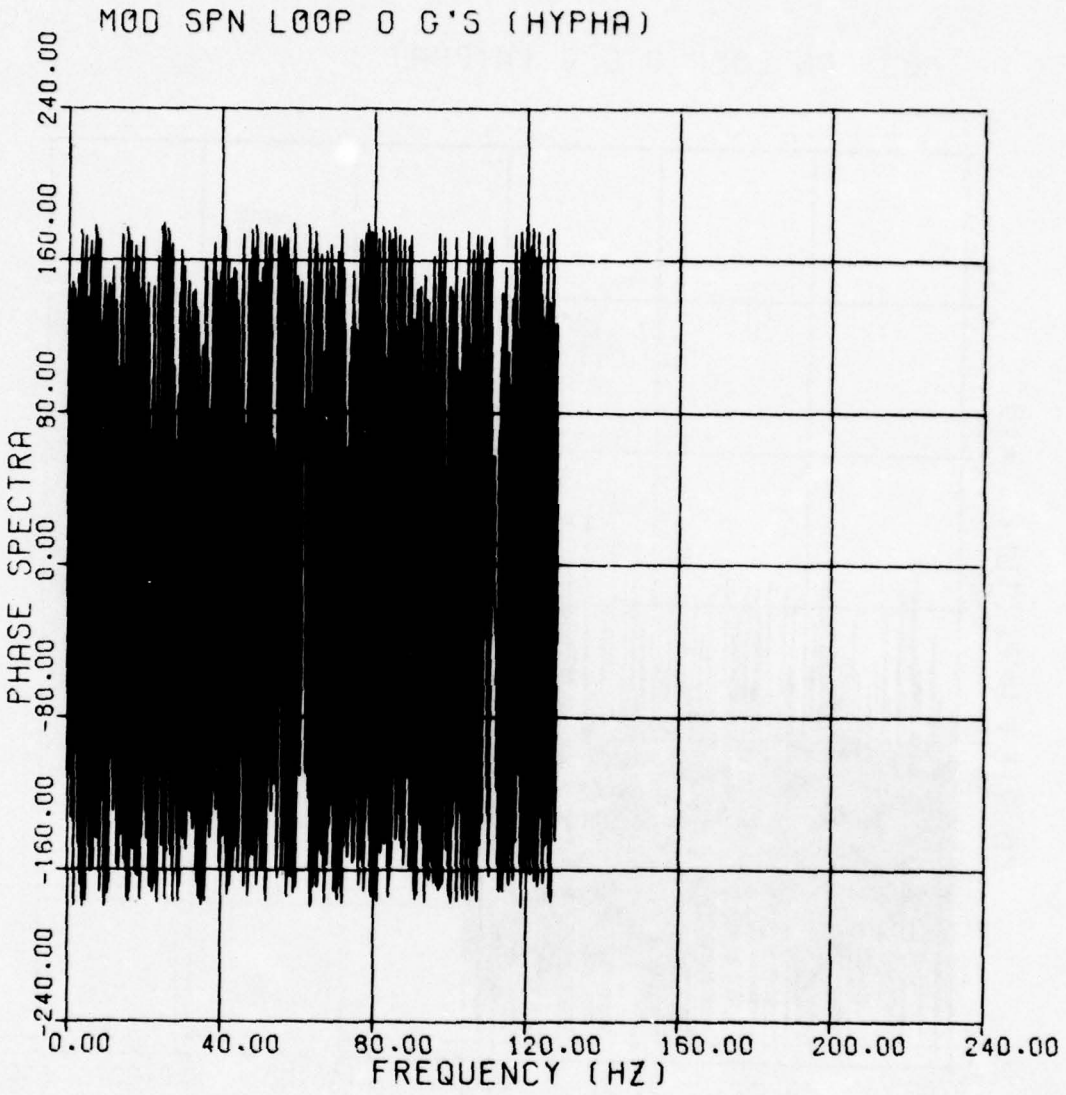


FIGURE 4.2-45. MOD SPN LOOP 0 g's (HYPHA)

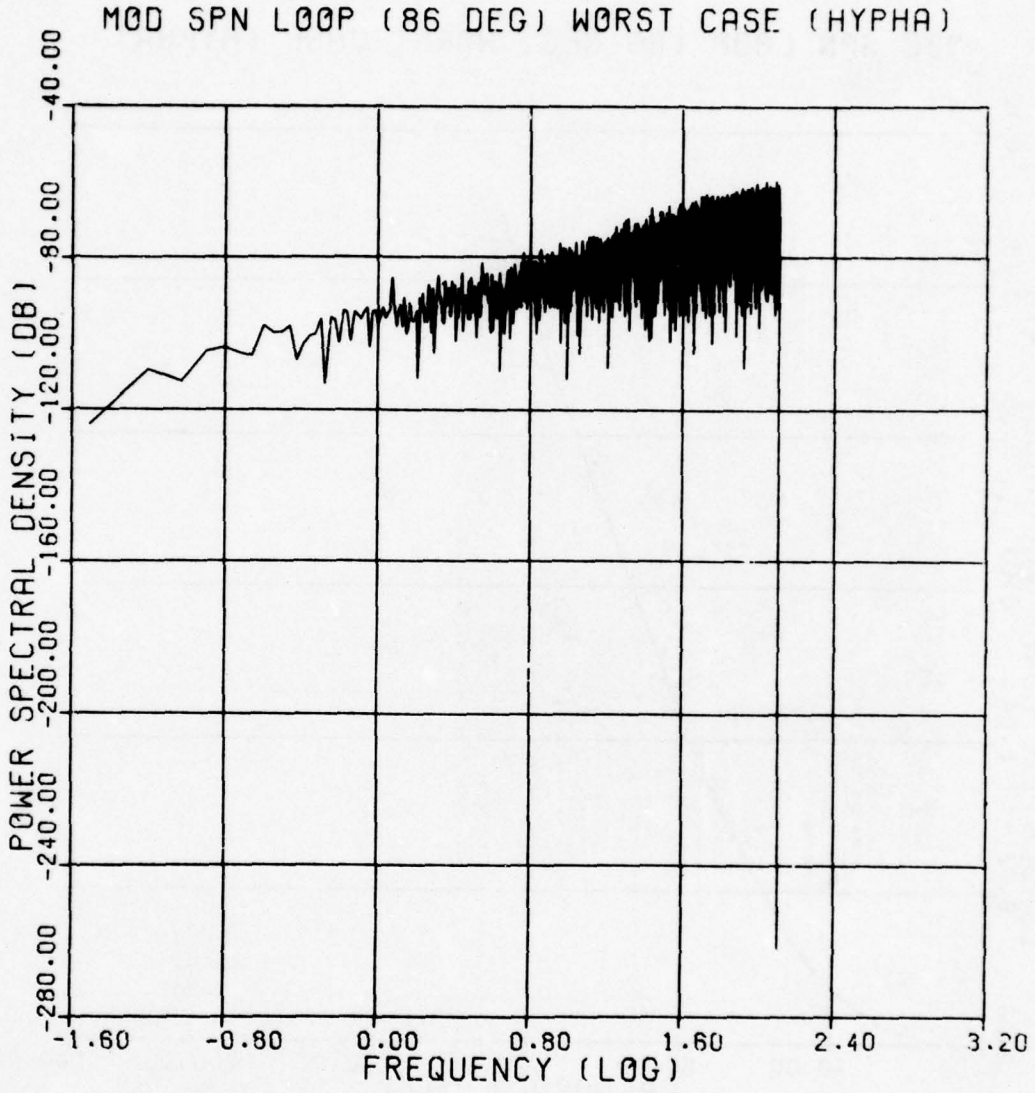


FIGURE 4.2-46. MOD SPN LOOP (86 DEGREES) WORST CASE (HYPHA)

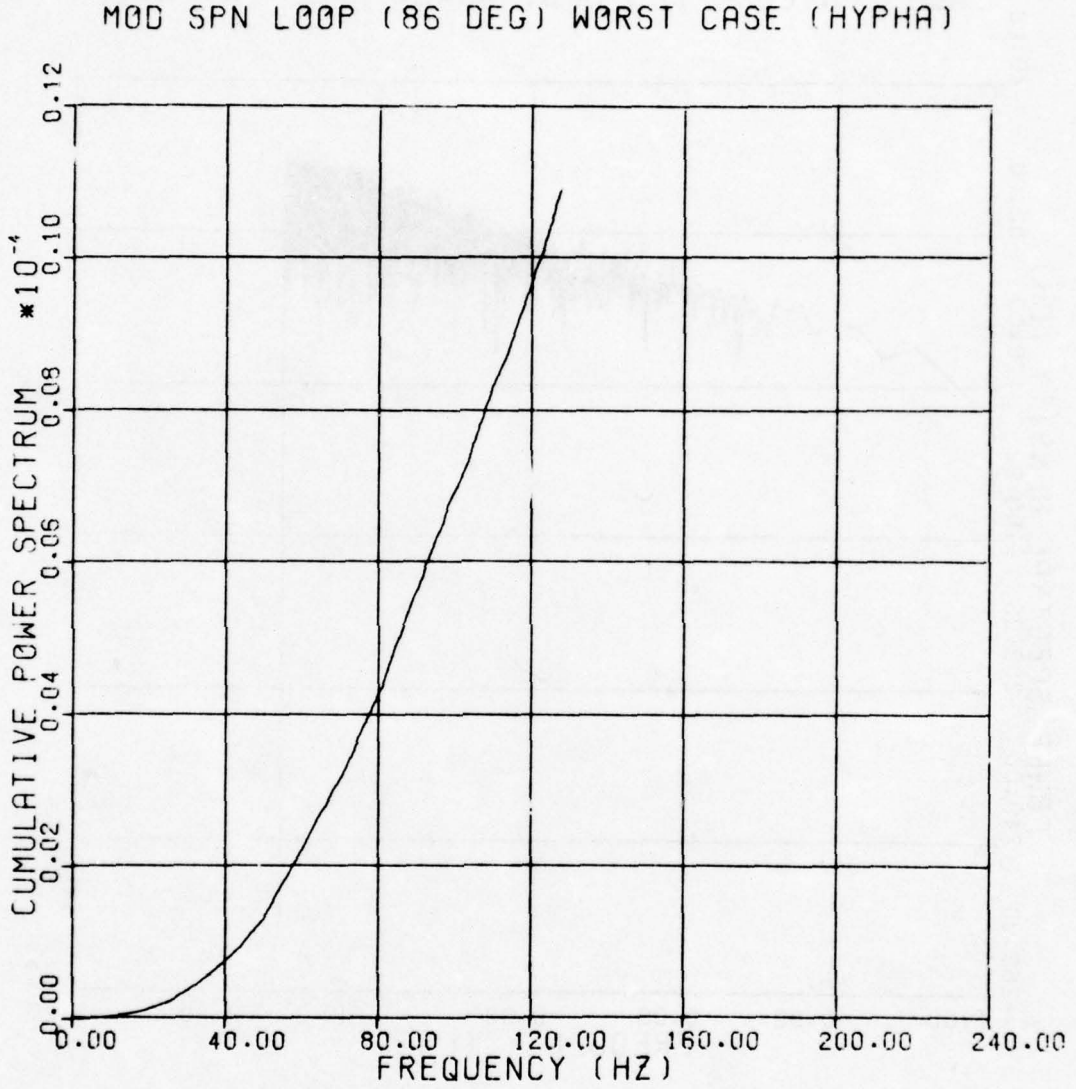


FIGURE 4.2-47. MOD SPN LOOP (86 DEGREES) WORST CASE (HYPHA)

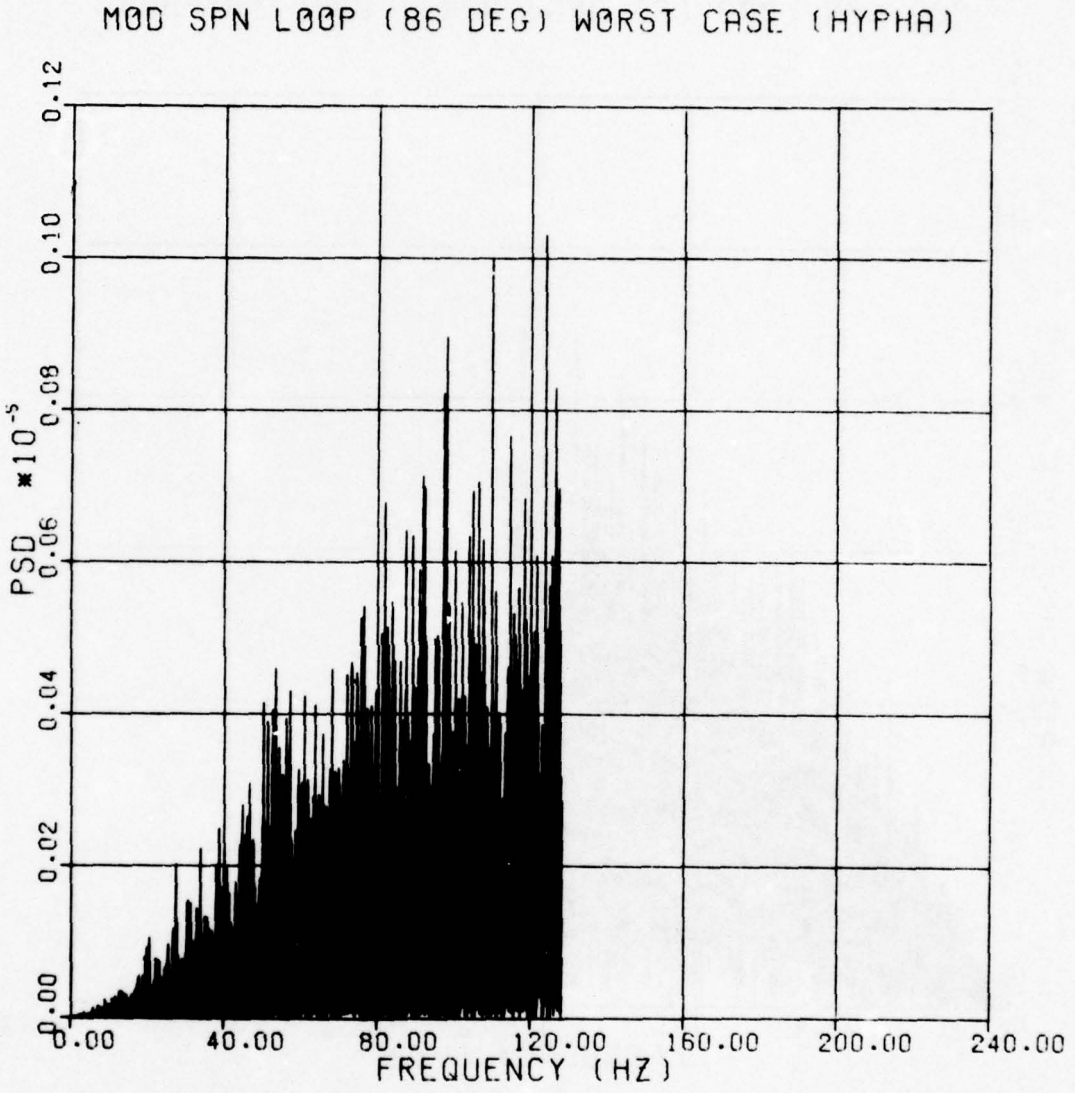


FIGURE 4.2-48. MOD SPN LOOP (86 DEGREES) WORST CASE (HYPHA)

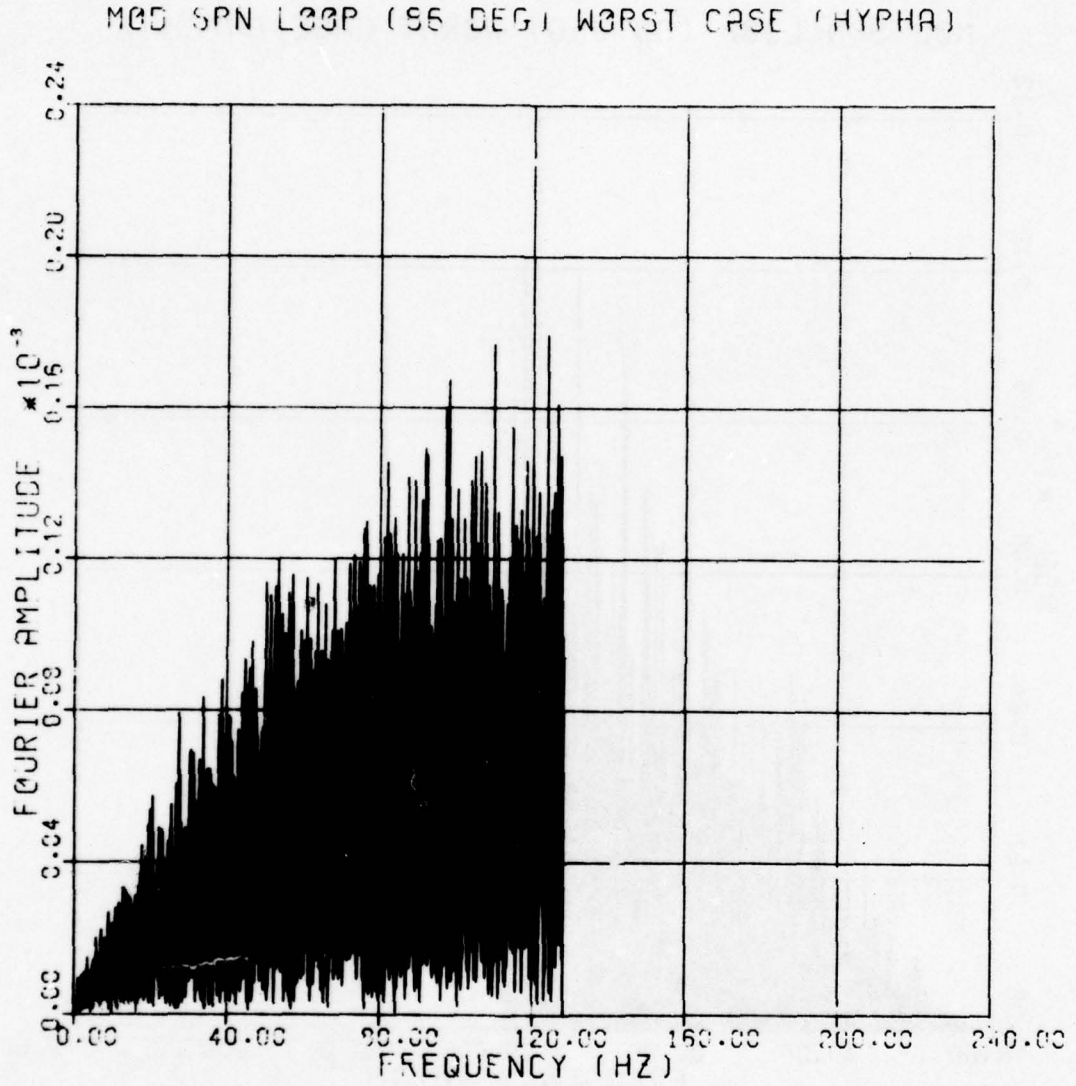


FIGURE 4.2-49. MOD SPN LOOP (86 DEGREES) WORST CASE (HYPHA)

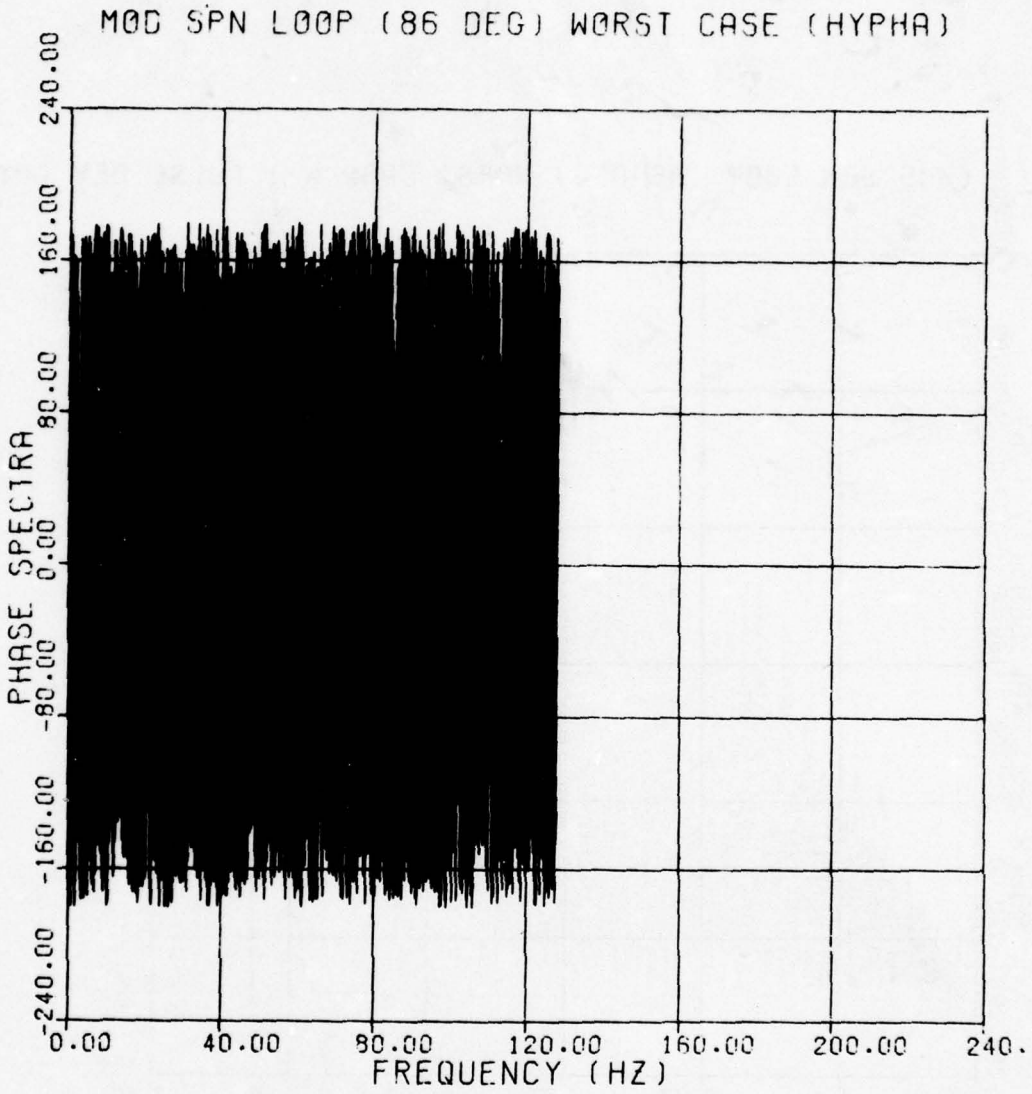


FIGURE 4.2-50. MOD SPN LOOP (86 DEGREES) WORST CASE (HYPHA)

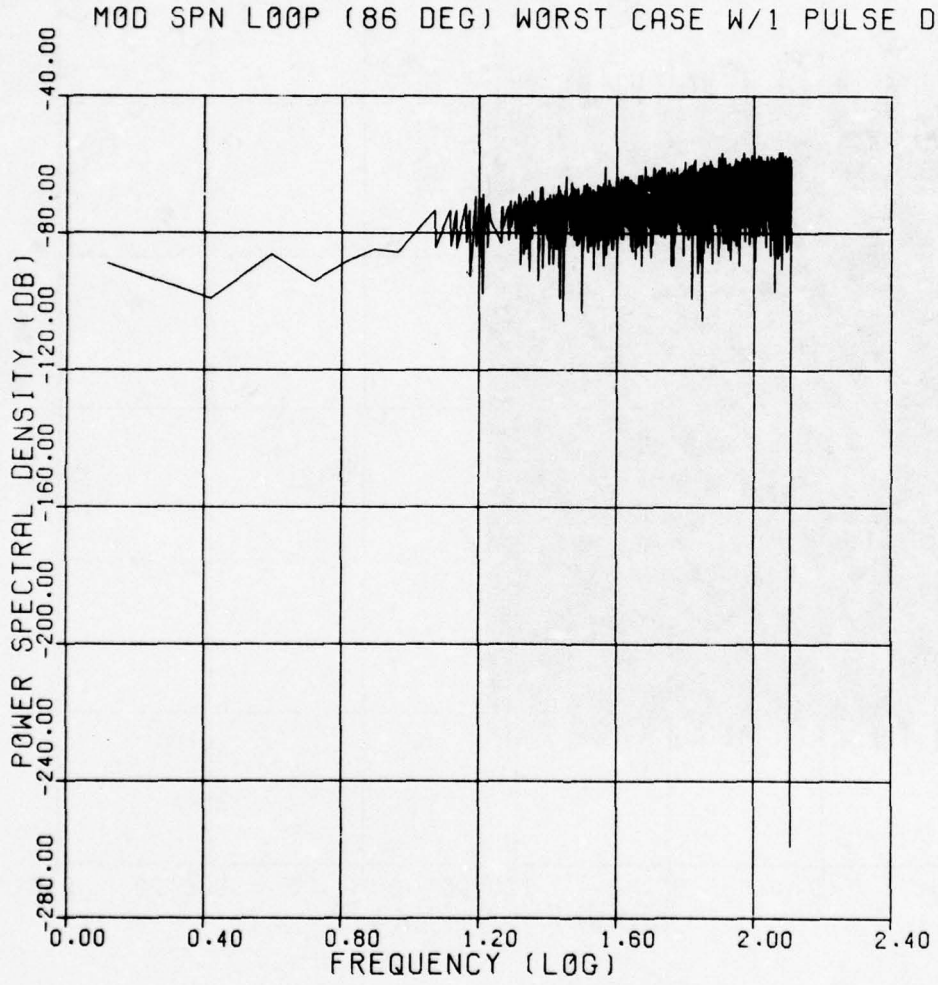


FIGURE 4.2-51. MOD SPN LOOP (86 DEGREES) WORST CASE W/1 PULSE DEV (HYPHA)

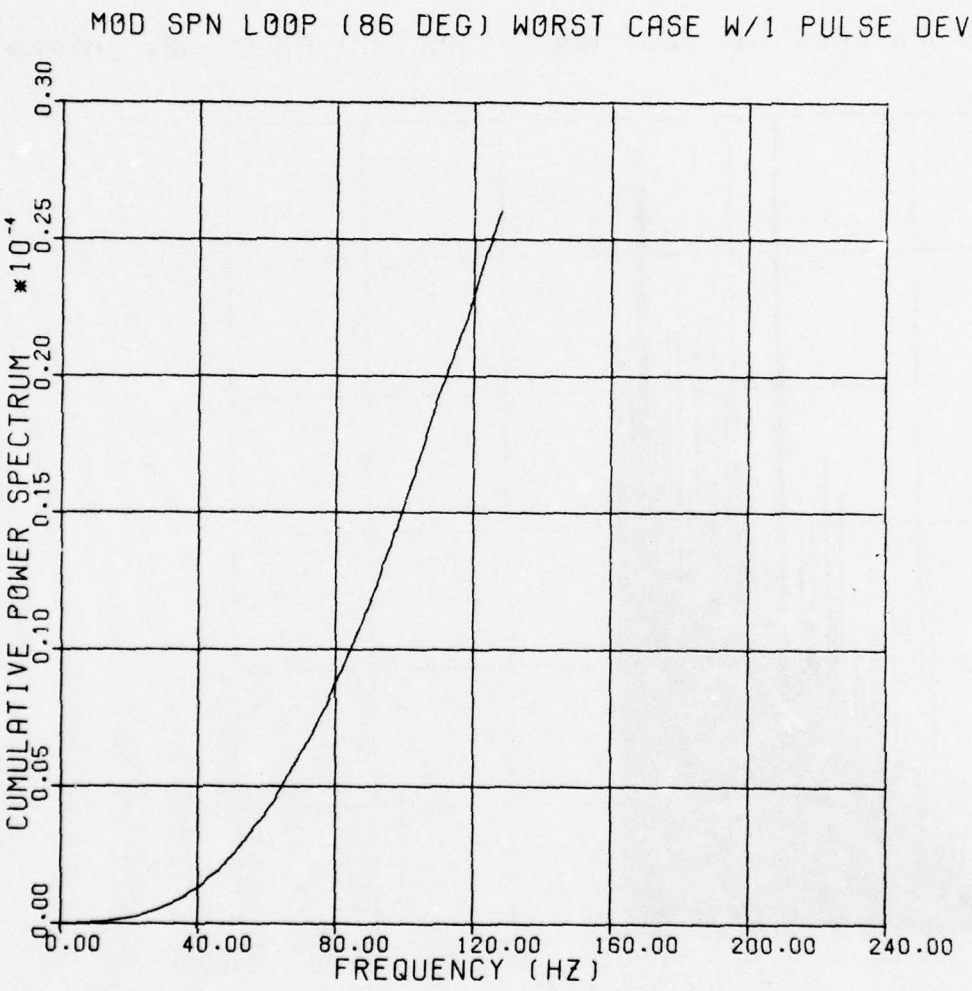


FIGURE 4.2-52. MOD SPN LOOP (86 DEGREES) WORST CASE W/1 PULSE DEV (HYPHA)

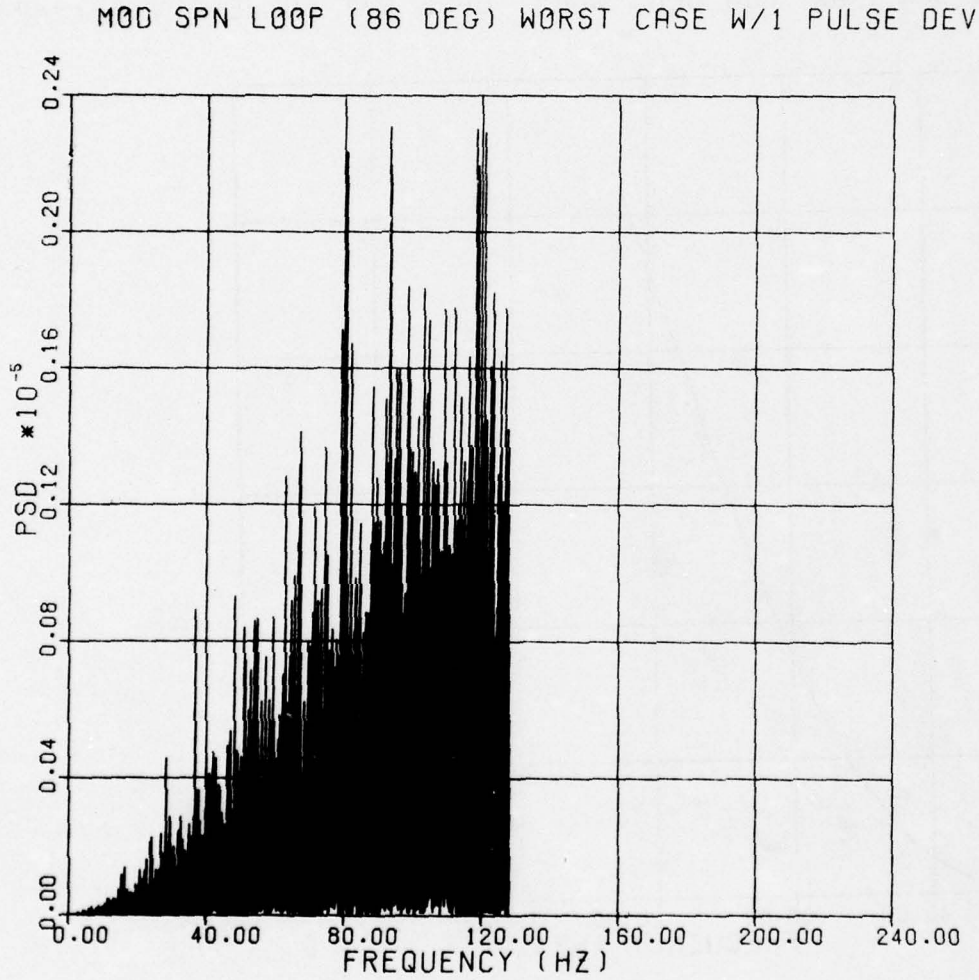


FIGURE 4.2-53. MOD SPN LOOP (86 DEGREES)
WORST CASE W/1 PULSE DEV (HYPHA)

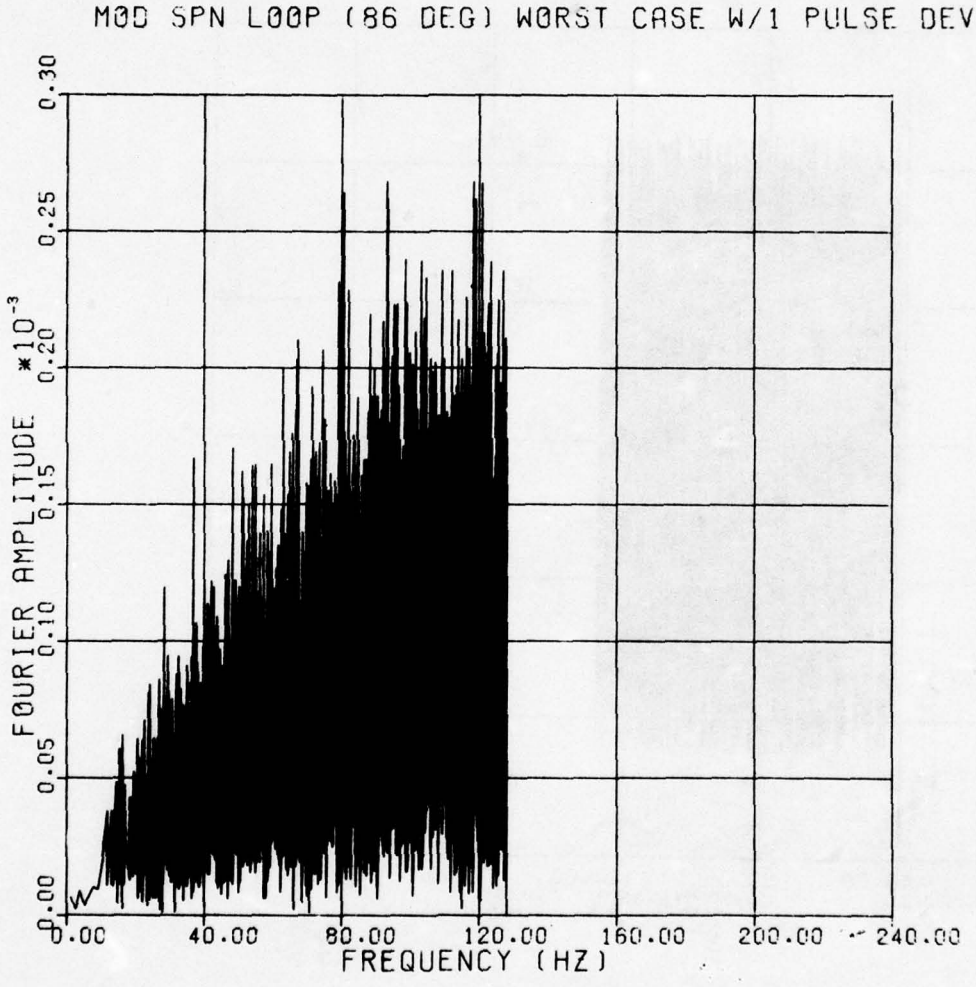


FIGURE 4.2-54. MOD SPN LOOP (86 DEGREES) WORST CASE W/1 PULSE DEV (HYPHA)

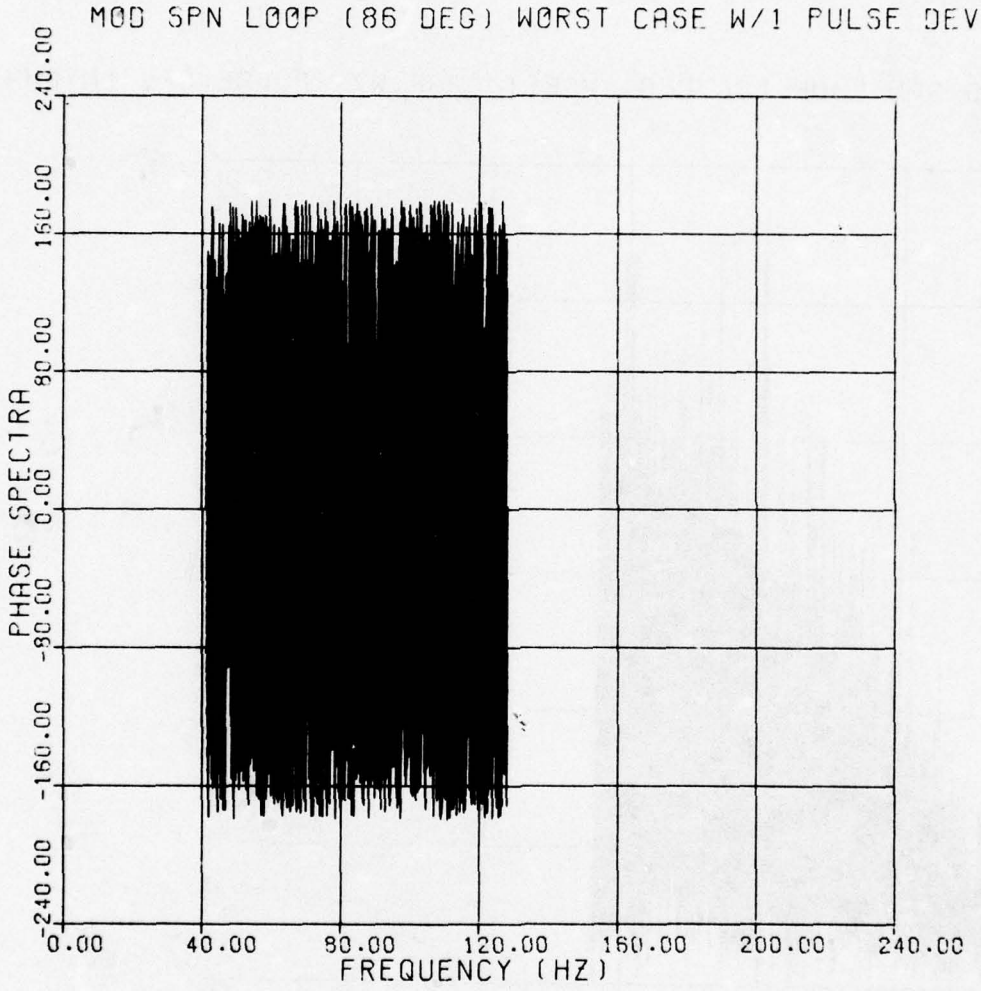


FIGURE 4.2-55. MOD SPN LOOP (86 DEGREES) WORST CASE W/1 PULSE DEV (HYPHA)

4.3 TEST CONSOLE CHANGES AND DATA PROCESSING HARDWARE

Upon resumption of effort, a new brassboard was constructed in order to eliminate possible noise and thermal problems. The concept used here differed from the original breadboard in that all loop circuits were physically in the same thermal environment as the accelerometer. Figure 4.3-1 and 4.3-2 show the construction of the brassboard. A VMU casting was used to mount a new DG177PG accelerometer (S/N VII). A tape cable header from SPN/GEANS was used with the identical accelerometer preamp circuit. Three circuit boards were constructed to fit on the casting. The common board, shown in Figure 4.3-3 contained the precision voltage supply, the torquer bridge, the signal generator excitation supply, the timing circuits and the ±12V supplies. This board remained mounted on the casting for either SPN/GEANS or HRPWM operation.

The other two boards were interchangeable in the other board position, one for SPN/GEANS and the other for HRPWM. See Figures 4.3-4 and 4.3-5 for schematics. Originally it was planned to use an analog loop board in conjunction with the common board and the HRPWM board for special accelerometer testing. The completion of this small board was later deferred because it was not needed. When the final HRPWM approach was tested, a new HRPWM board was not fabricated. Instead, the SPN/GEANS board was modified, and the new demod built on the old analog board.

Along with the new brassboard block, a new cable and control panel were constructed. See Figures 4.3-6 and 4.3-7 for schematics. The control panel contained the Hypha interpolator circuit and a new data processing board. See Figures 4.3-8 and 4.3-9 for schematics. The data processing hardware is shown in Figure 4.3-10. A Honeywell 516 computer with a GEANS serial data bus interface was used with two Honeywell tape decks and a teletypewriter. Software was written to collect data from the data bus, record all data on mag tape, and calculate the mean and the deviation of each record of 1024 data samples. See appendix for Software listing.

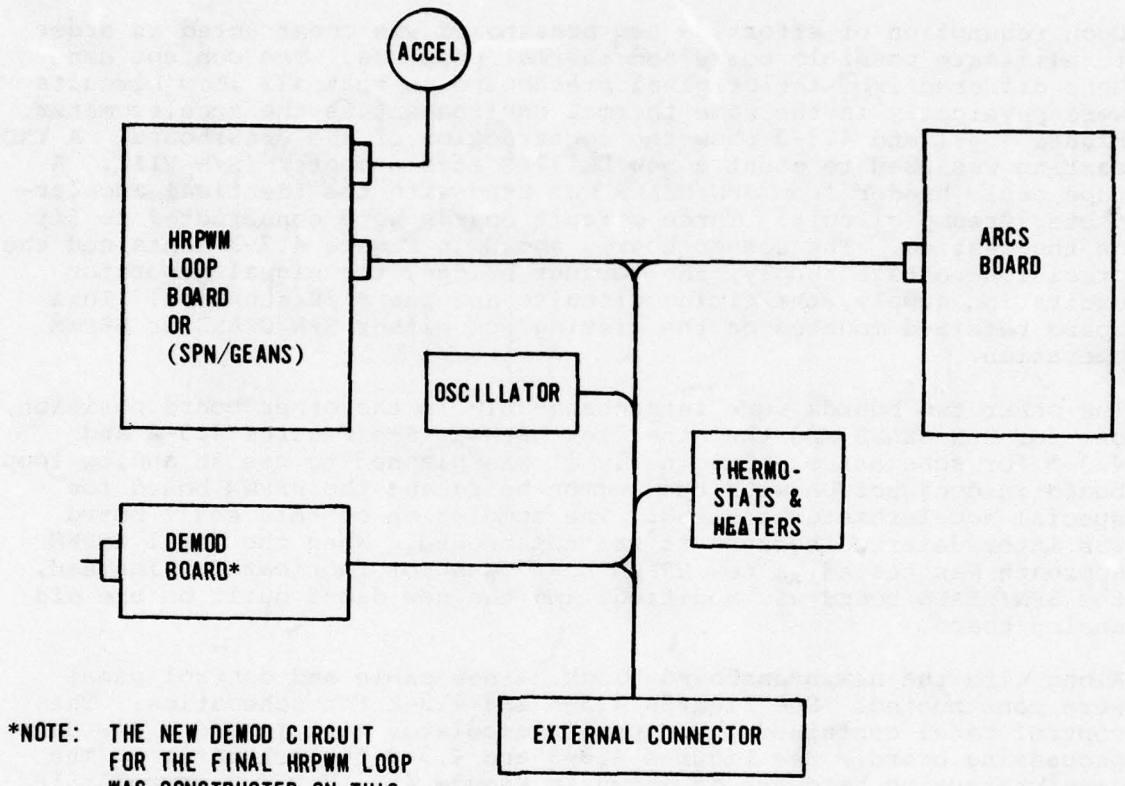


FIGURE 4.3-1. EARS BRASSBOARD

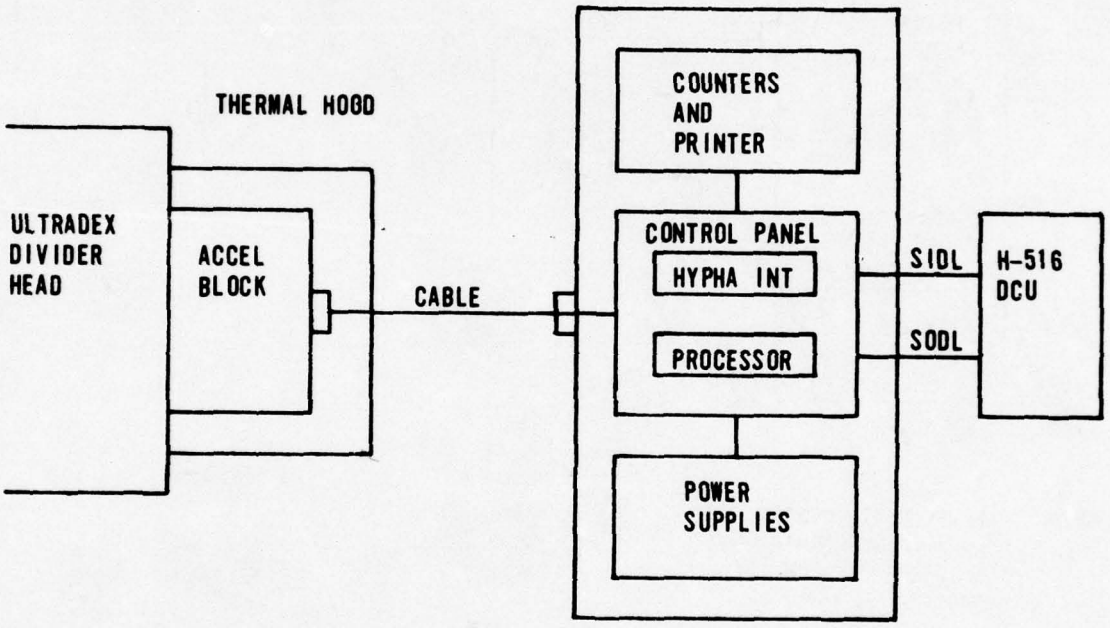
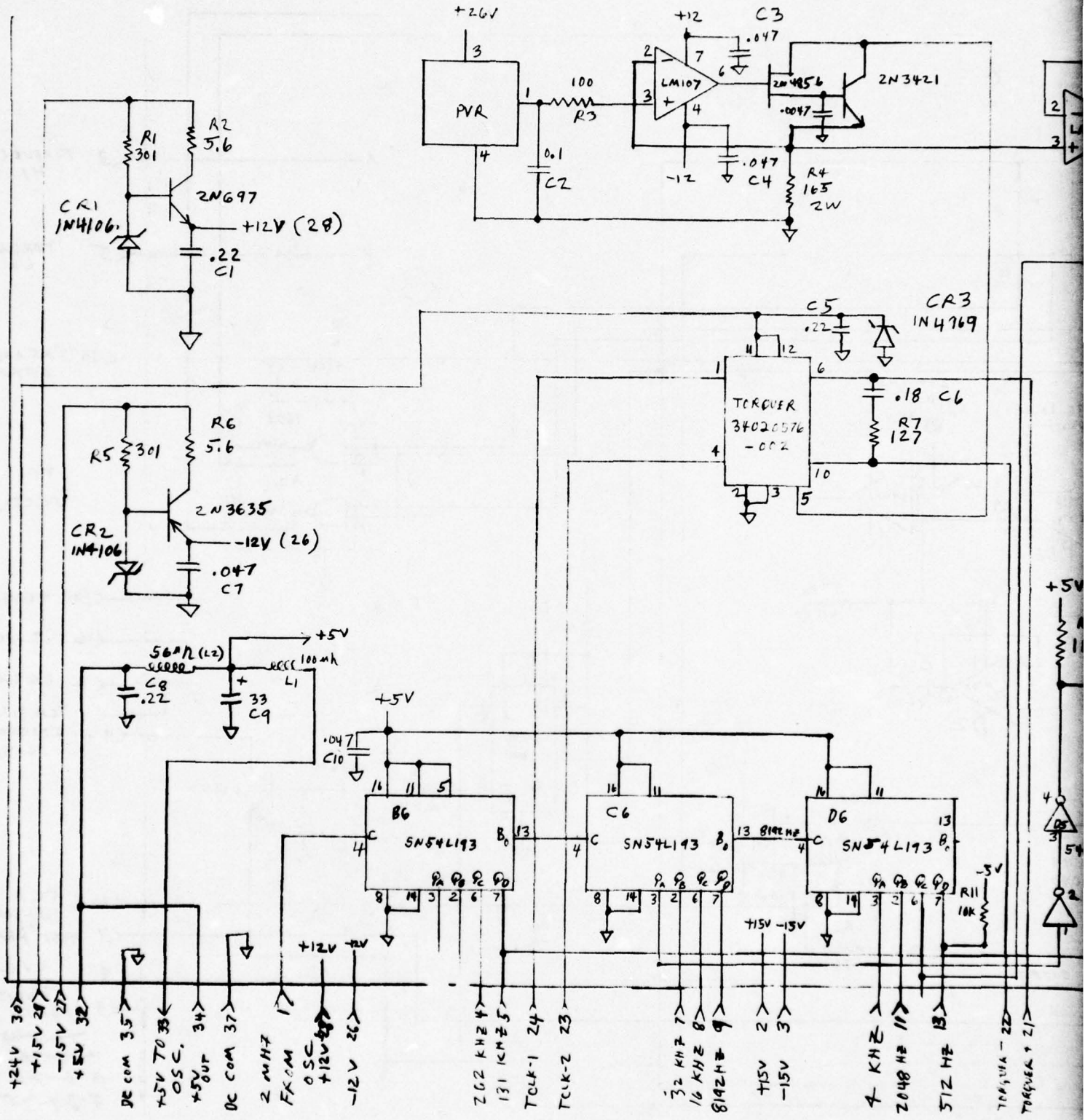


FIGURE 4.3-2. EAR BRASSBOARD TEST SETUP


+26V
PVR
100
R3
0.1
C2
+12
C3
.047
LM107
2N4856
2N3421
.0047
-12
.047
C4
R4
165
2W
R1
301
R2
5.6
2N697
CR1
IN4106
+12V (28)
.22
C1
C5
.22
CR3
IN4769
TORQUER
3402576
-002
.18 C6
R7
127
R6
5.6
R5
301
2N3635
CR2
IN4106
-12V (26)
.047
C7
+5V
56Ω (L2)
100 mh
L1
C8
.22
33
C9
+5V
.047
C10
B6
SN54L193
C6
SN54L193
D6
SN54L193
8192 HZ
-5V
R11
10K
+15V -15V
+24V 30
+15V 29
-15V 27
+5V 32
DC COM 35
+5V TO OSC.
+5V OUT 34
DC COM 37
2 MHZ FROM OSC
+12V
-12V 26
262 KHZ 4
131 KHZ 5
TCLK-1 24
TCLK-2 23
32 KHZ 7
16 KHZ 8
8192HZ 9
+15V 2
-15V 3
4 KHZ
2048 HZ 11
512 HZ 13
TORQUER - 22
TORQUER + 21

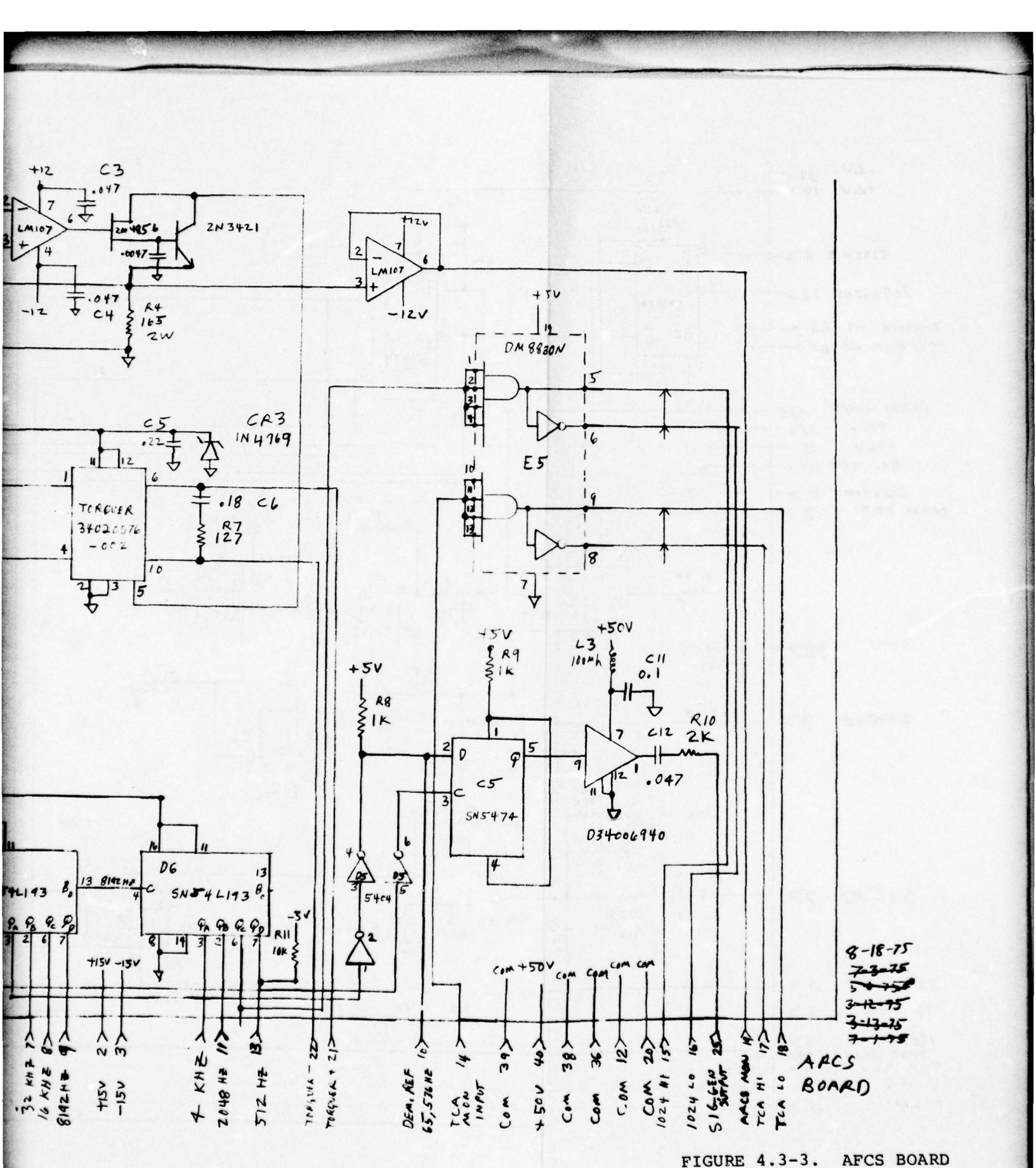
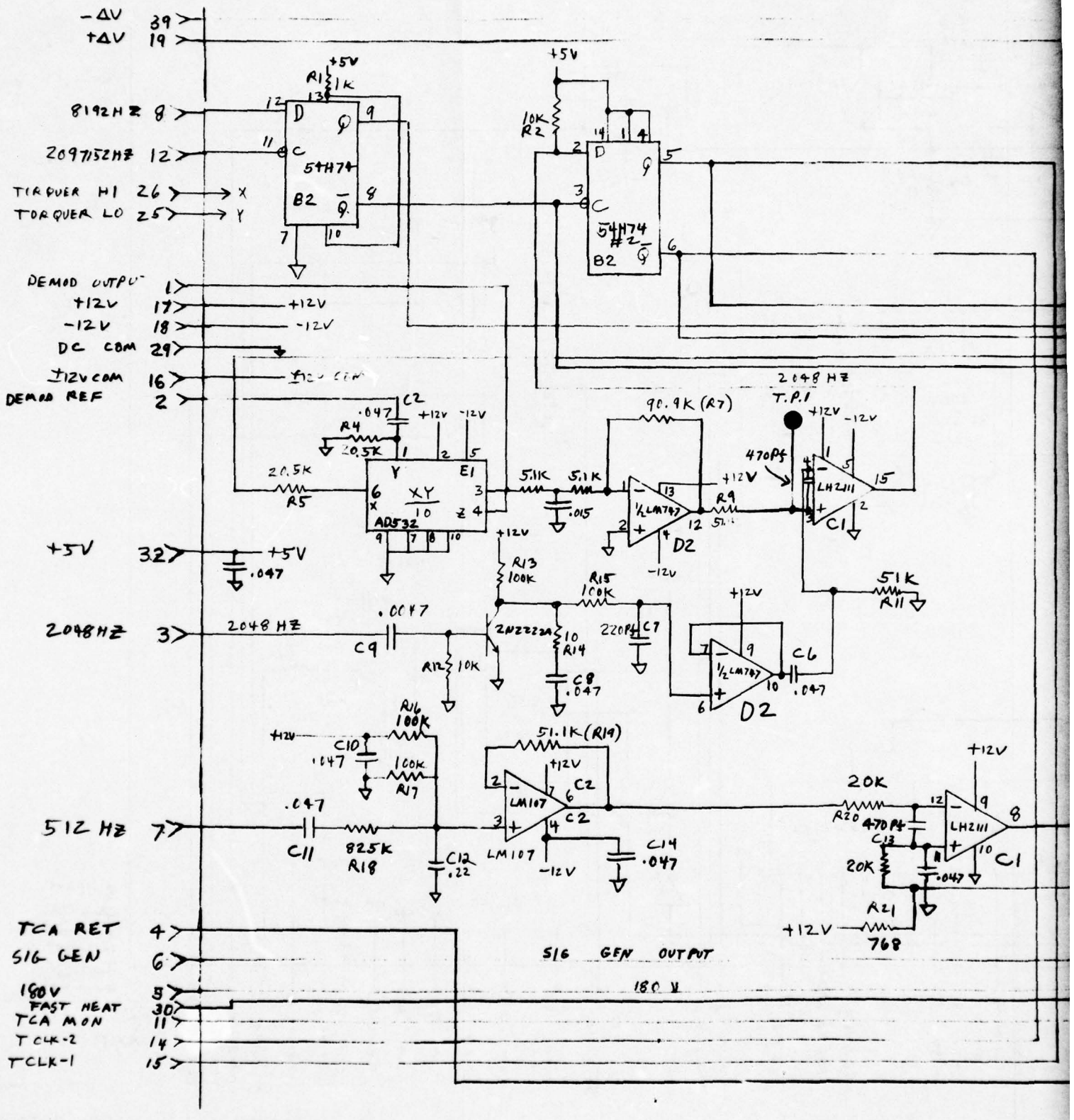


FIGURE 4.3-3. AFCS BOARD


-ΔV 39
+ΔV 19
8192 HZ 8
2097152HZ 12
TORQUER HI 26 → X
TORQUER LO 25 → Y
DEMOD OUTPUT 1
+12V 17
-12V 18
DC COM 29
±12V COM 16
DEMOD REF 2
+5V 32
2048 HZ 3
512 HZ 7
TCA RET 4
SIG GEN 6
180V 5
FAST HEAT 30
TCA MON 11
TCLK-2 14
TCLK-1 15
R1 1K
+5V
54H74
B2
10K R2
54H74 #2
C2 .047
R4 20.5K
20.5K R5
AD532
5.1K
5.1K
.015
90.9K (R7)
R9
1/4 LM747
D2
T.P.1
470Pf
LH2111
C1
R13 100K
R15 100K
51K R11
.0047 C9
2N2222A
10 R14
220Pf C7
R12 10K
C8 .047
C6 .047
R16 100K
C10 .047
100K R17
51.1K (R19)
LM107
C2
.047 C11
825K R18
C12 .22
C14 .047
20K R20
470Pf C13
20K
.047
R21 768
SIG GEN OUTPUT
180 V

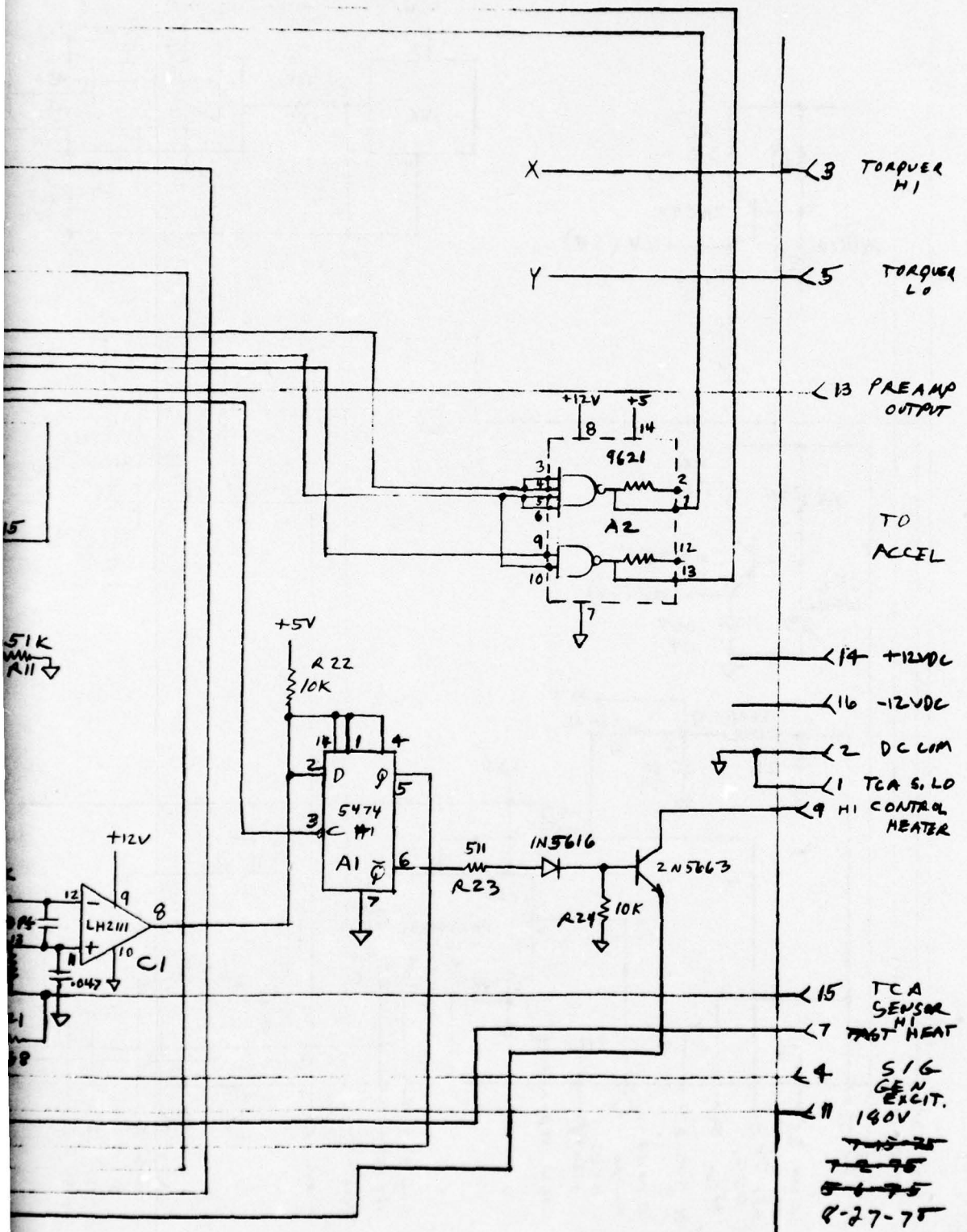


FIGURE 4.3-4. SPN/GEANS LOOP BOARD

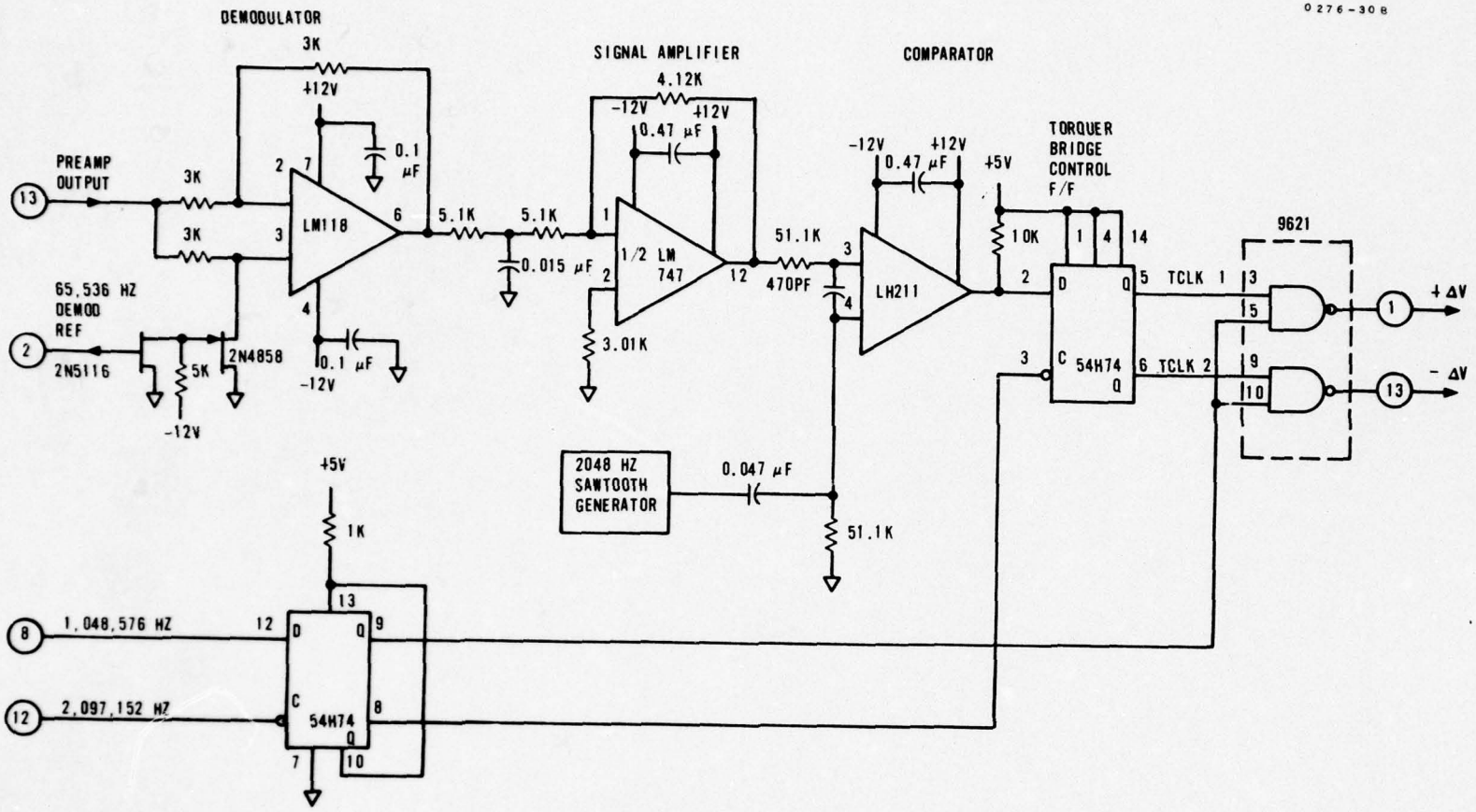
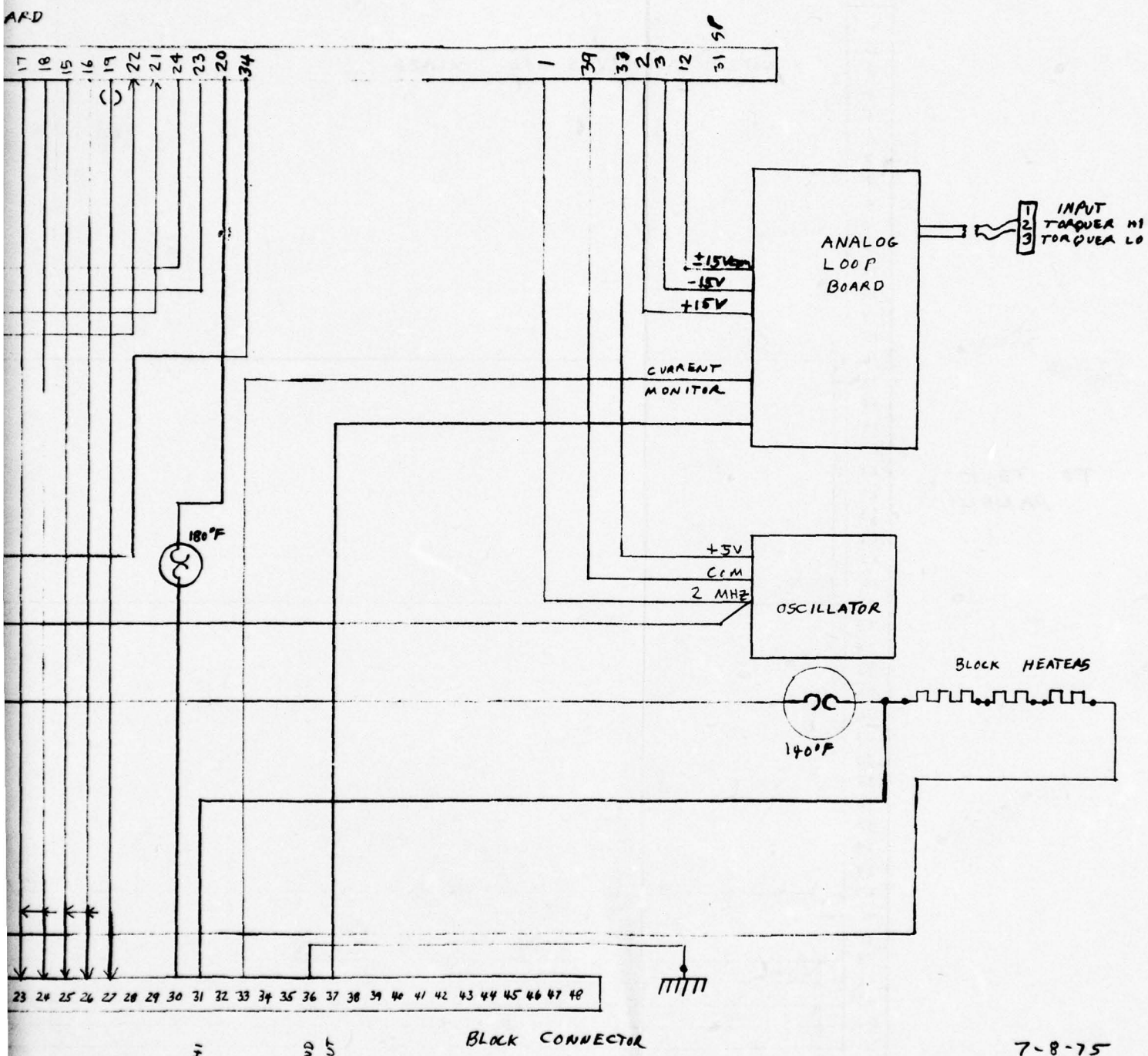


FIGURE 4.3-5. HRPWM BOARD SCHEMATIC

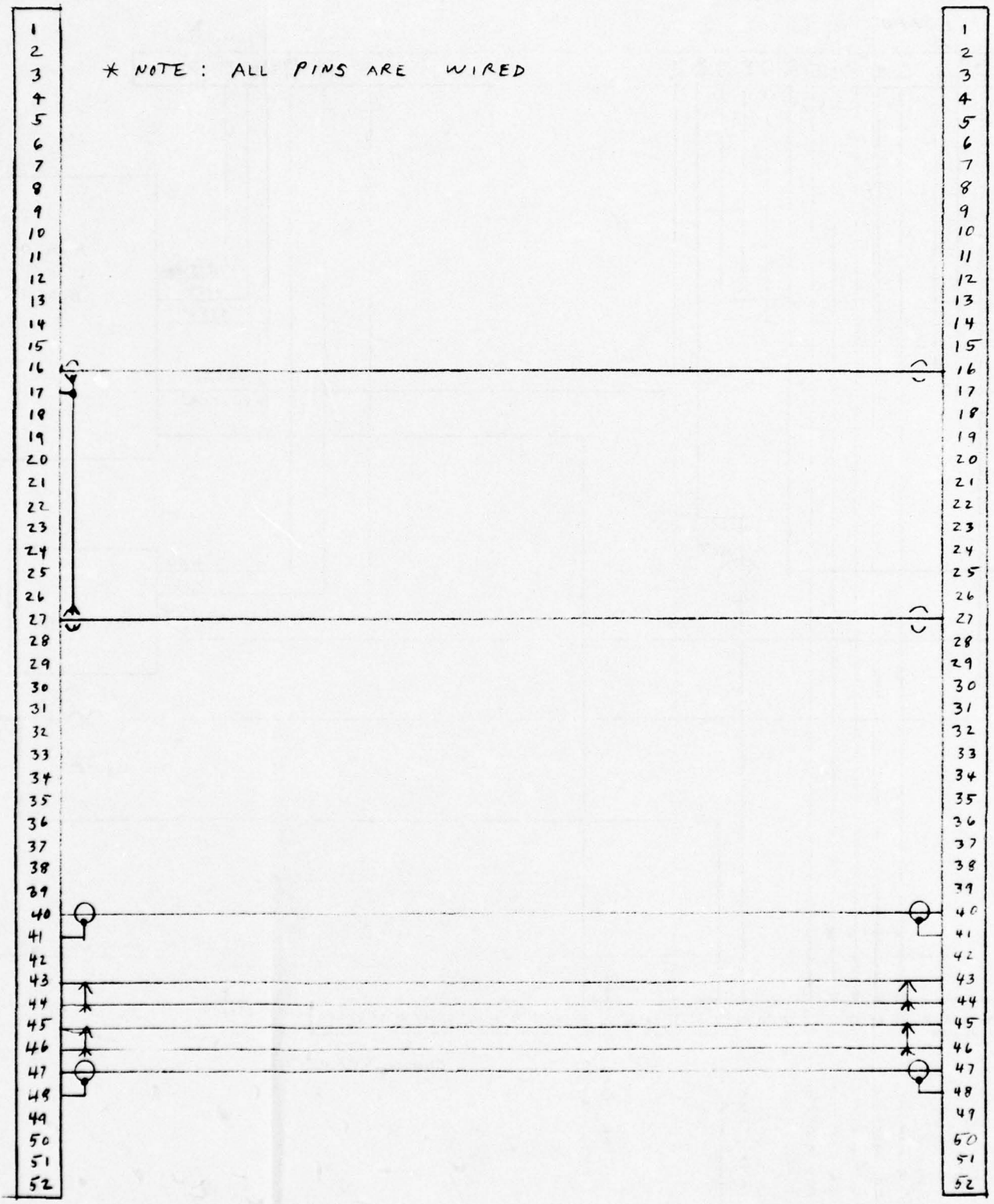
ARCS BOARD
DIGITAL LOOP BOARD
FAST HEAT
DC COM
TCLK 1
TCLK 2
TORQUER OUT HI
TORQUER OUT LO
131 KHZ
4 KHZ
32 KHZ
16 KHZ
262 KHZ
±12V COM
-12V DC
+12VDC
DEMOD OUTPUT
+5V IN
-ΔV
+ΔV
2 MHZ
2048 HZ
9192 HZ
512 HZ
SIG GEN EXCIT
DEMOD REF
TCA RETURN
TCA MON
180V
180°F
180VDC
+15VDC
-15VDC
DC COM
+5VDC
+180VDC
BLOCK HEAT LO
TCA RET
+24VDC
+50VDC
DC COM
+ΔV
-ΔV
DEMOD OUTPUT
FAST HEAT
TCA MON HI
TCA MON LO
1024 CLK HI
1024 CLK LO
ARCS MONITOR
OVER-TEMP
BLOCK HTR. HI
CASE GND
SIG. INPUT

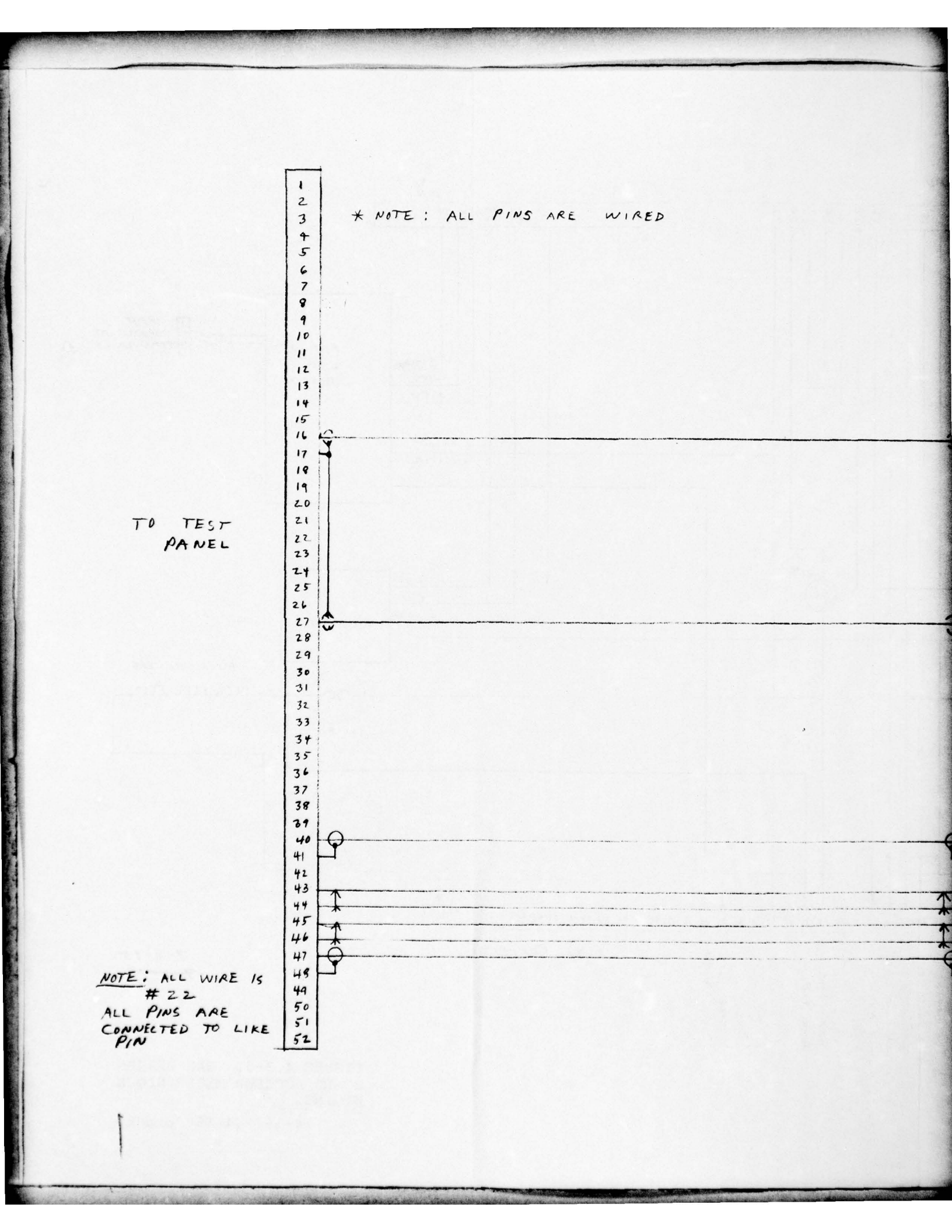


7-8-75

~~7-1-75~~

FIGURE 4.3-6. EAR BRASS-BOARD ACCELEROMETER BLOCK WIRING


* NOTE : ALL PINS ARE WIRED
TO TEST PANEL
E: ALL WIRE IS #22
PINS ARE NECTED TO LIKE N


* NOTE: ALL PINS ARE WIRED
TO TEST PANEL
NOTE: ALL WIRE IS #22
ALL PINS ARE CONNECTED TO LIKE PIN

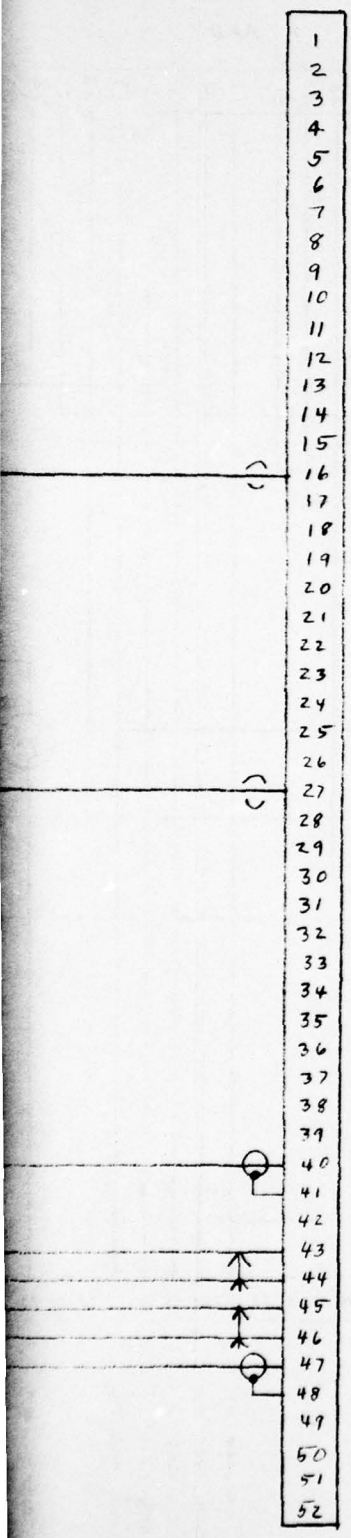
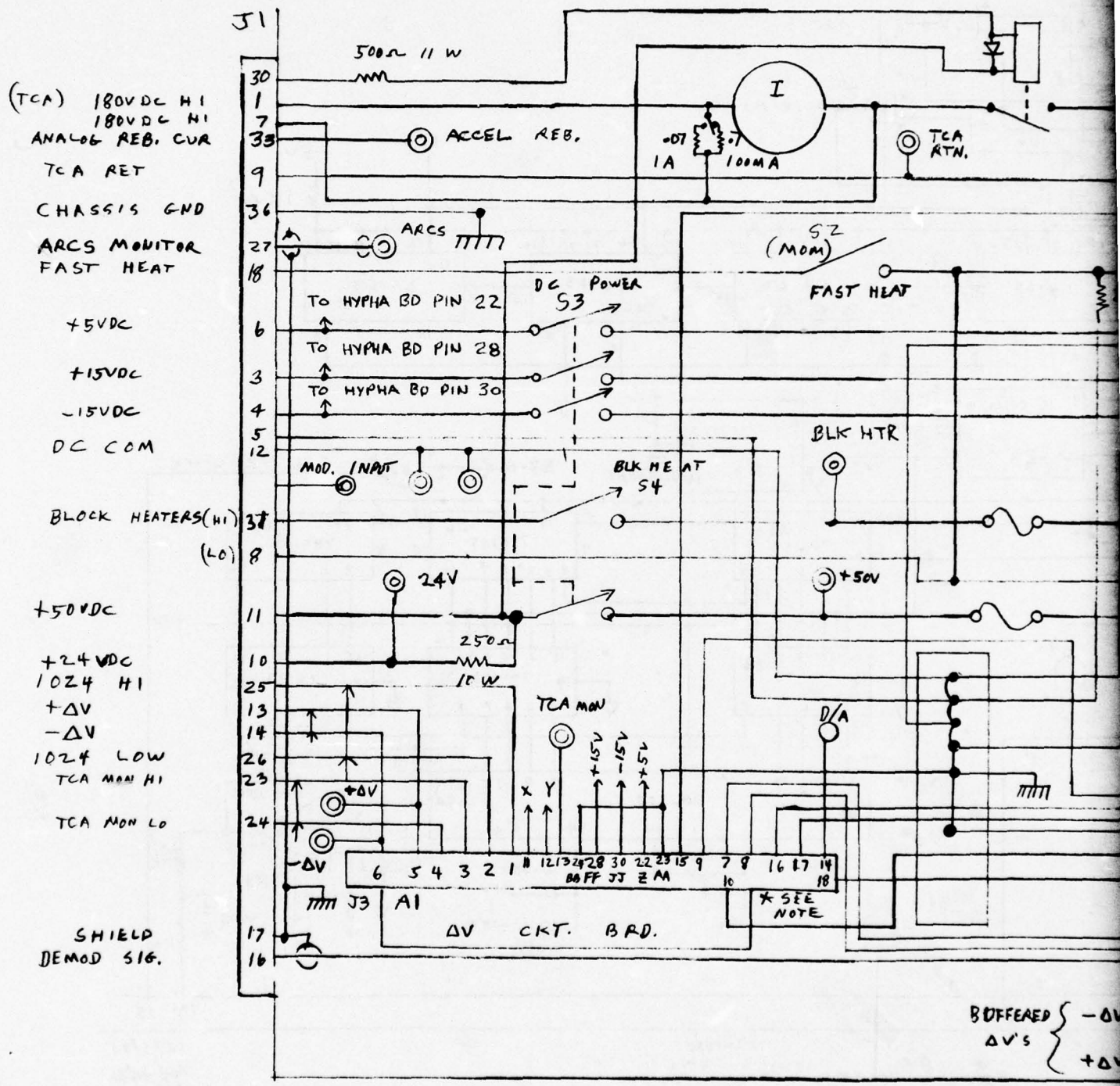
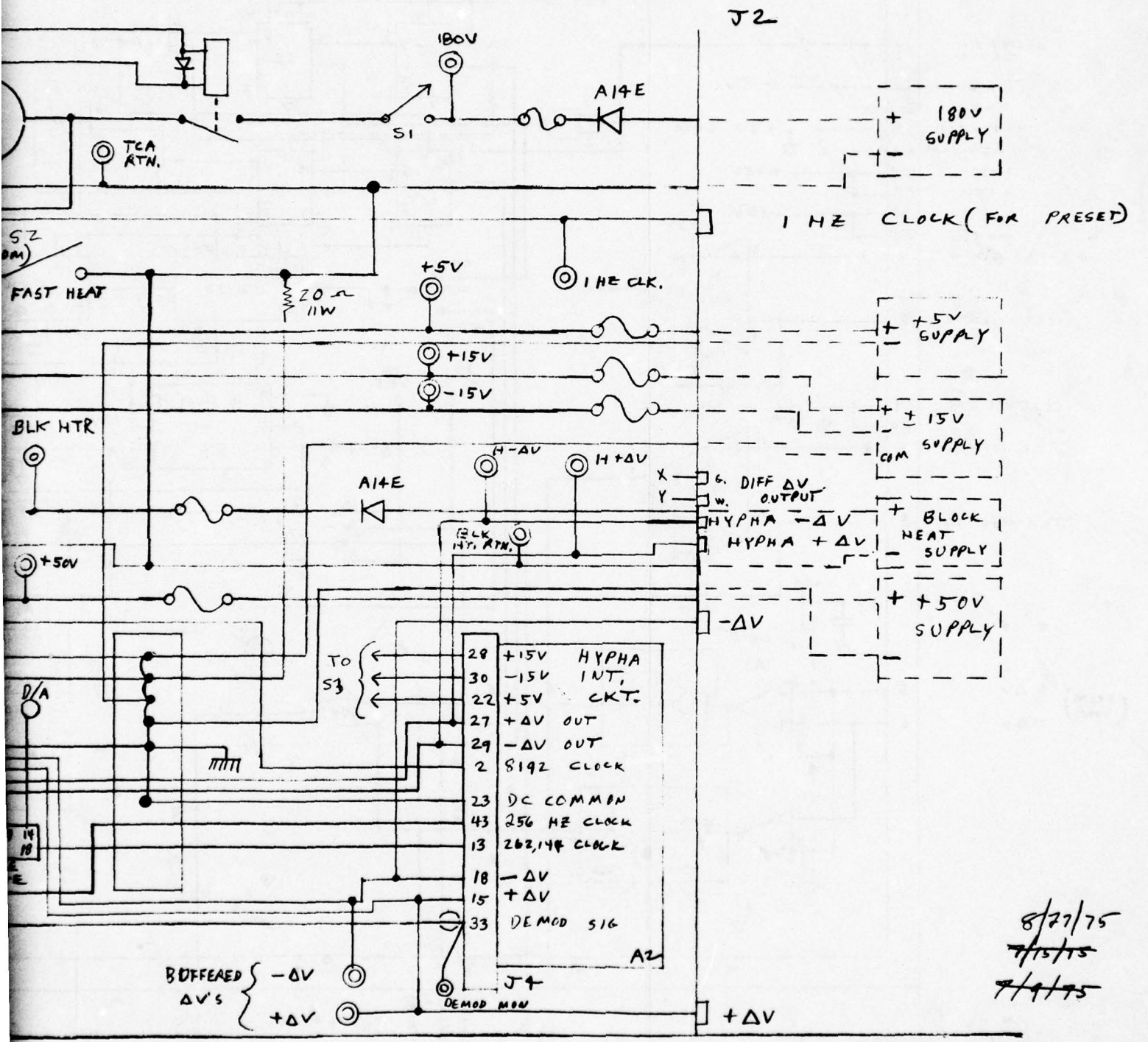


FIGURE 4.3-7. EAR BRASS-BOARD TEST CABLE

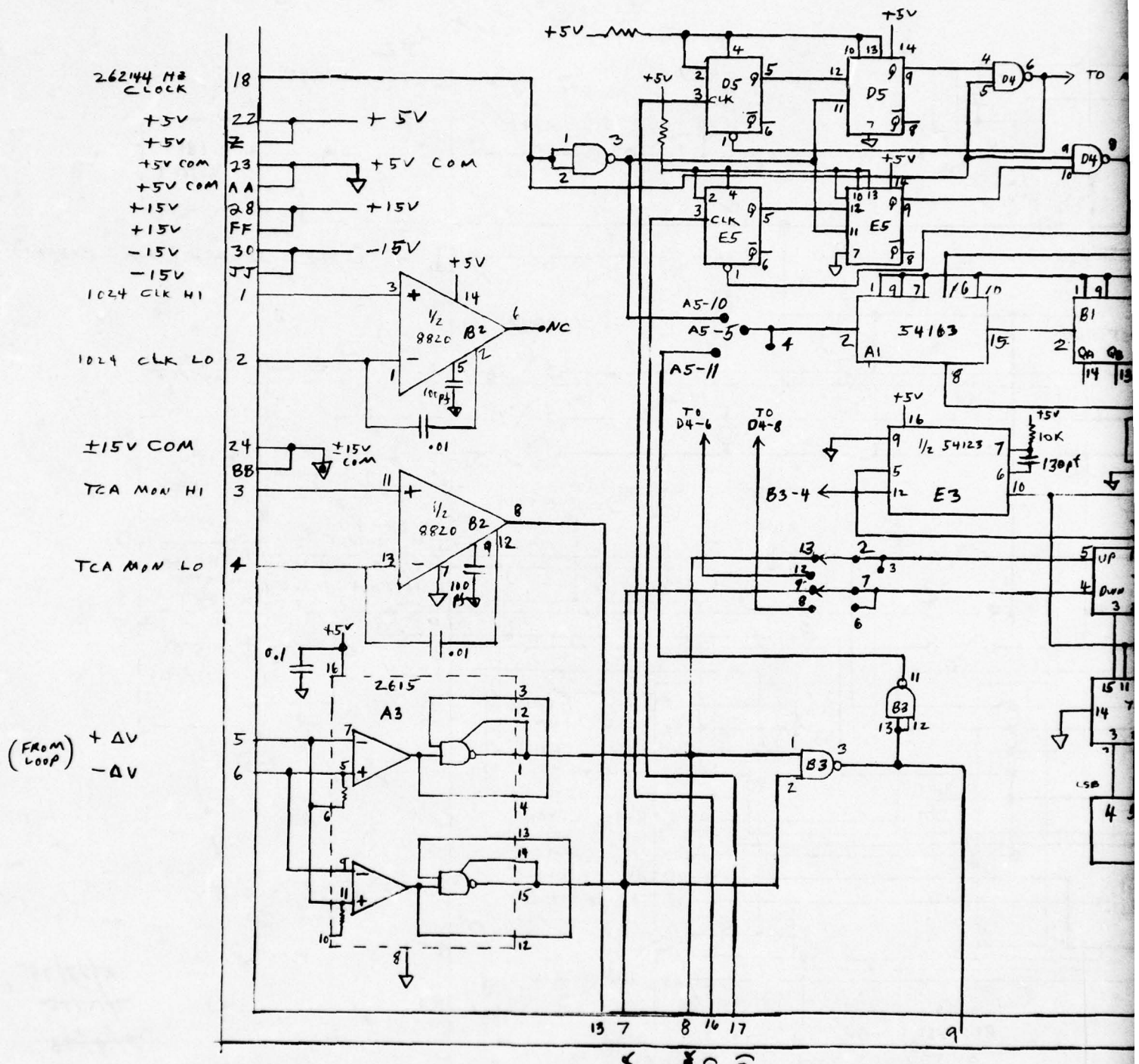


NOTE: PINS 32→37 OF A1 ARE USED FOR SERIAL DATA BUS CONNECTION, SEE PRINT

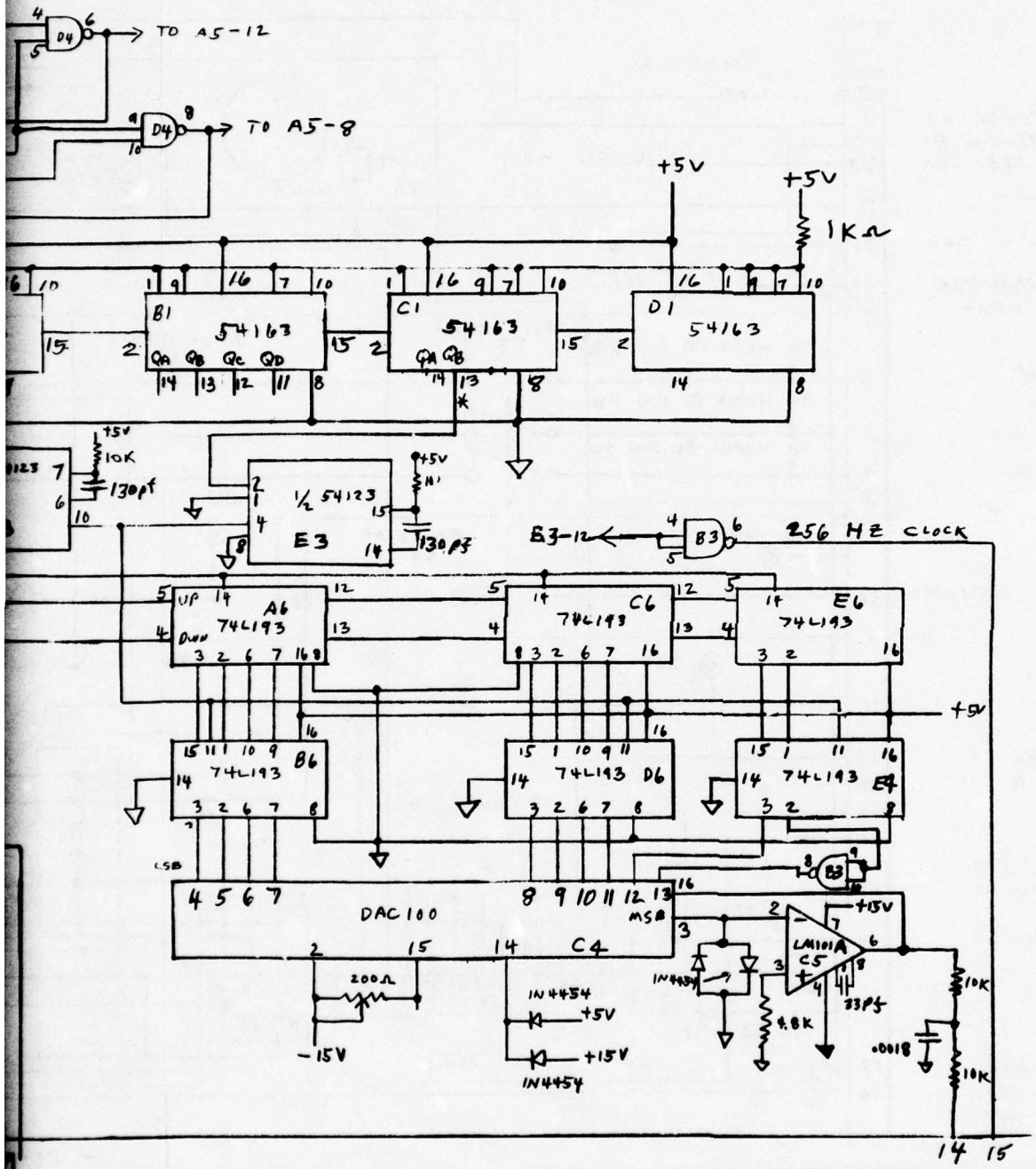


8/27/75
~~7/15/75~~
~~7/9/75~~

FIGURE 4.3-8. EAR BRASSBOARD CONTROL PANEL



* THIS CONNECTION IS SHOWN AS USED FOR A 256 HZ DATA RATE IN THE HYPHA MODE, OTHR DATA RATES OBTAINED BY MOVING TO OTHER FAFO.



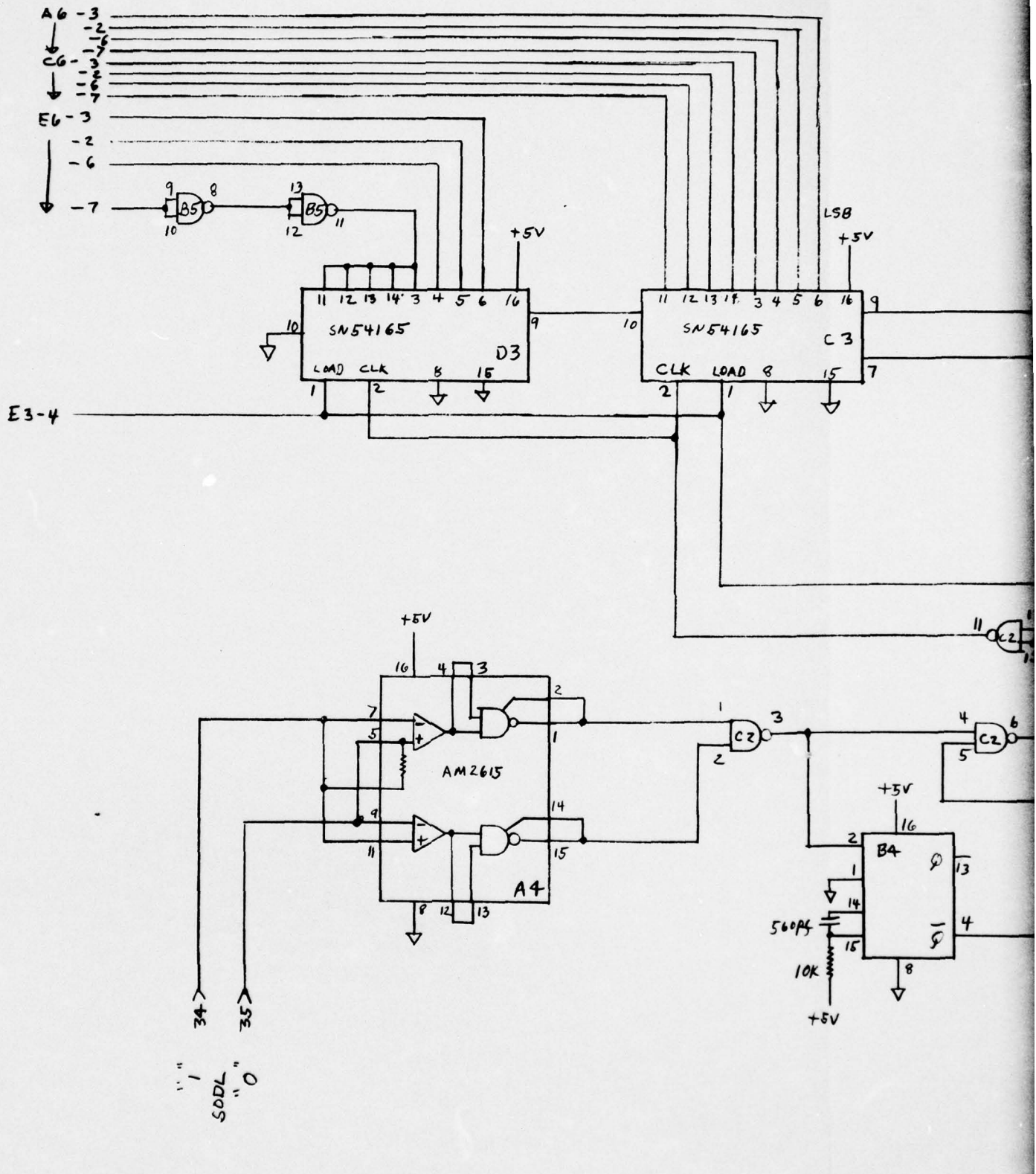
JUMPERS

HAPWM	A5-13	TO	A5-2
	A5-9	TO	A5-6
	A5-11	TO	A5-4
HYPHA	A5-12	TO	A5-3
	A5-8	TO	A5-7
	A5-10	TO	A5-5

ΔV CLOCK TO HYPHA (8192)

12/3/75
~~12/26/75~~
7/16/75

FIGURE 4.3-9. EAR BRASS-BOARD PROCESSOR BOARD (Sheet 1 of 2)
4-173/(4-174 blank)


A6 -3
-2
-6
-7
C6 -3
-2
-6
-7
E6 -3
-2
-6
-7
B5
B5
+5V
LSB
+5V
SN54165
D3
LOAD CLK
SN54165
C3
CLK LOAD
E3-4
+5V
AM2615
A4
+5V
B4
560pf
10K
+5V
34
35
SODL
"1"
"0"

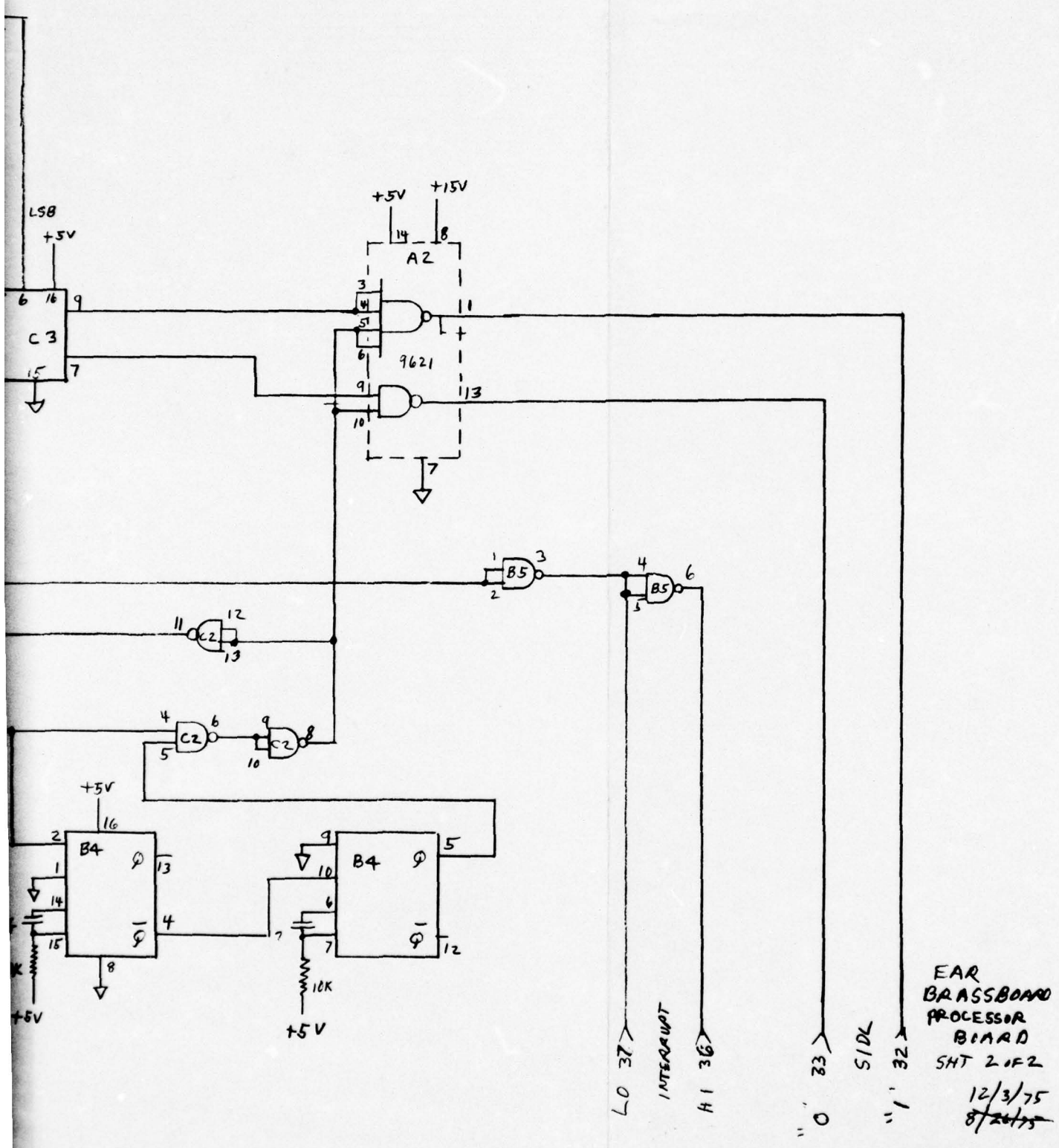


FIGURE 4.3-9. EAR BRASS-BOARD PROCESSOR BOARD (Sheet 2 of 2)

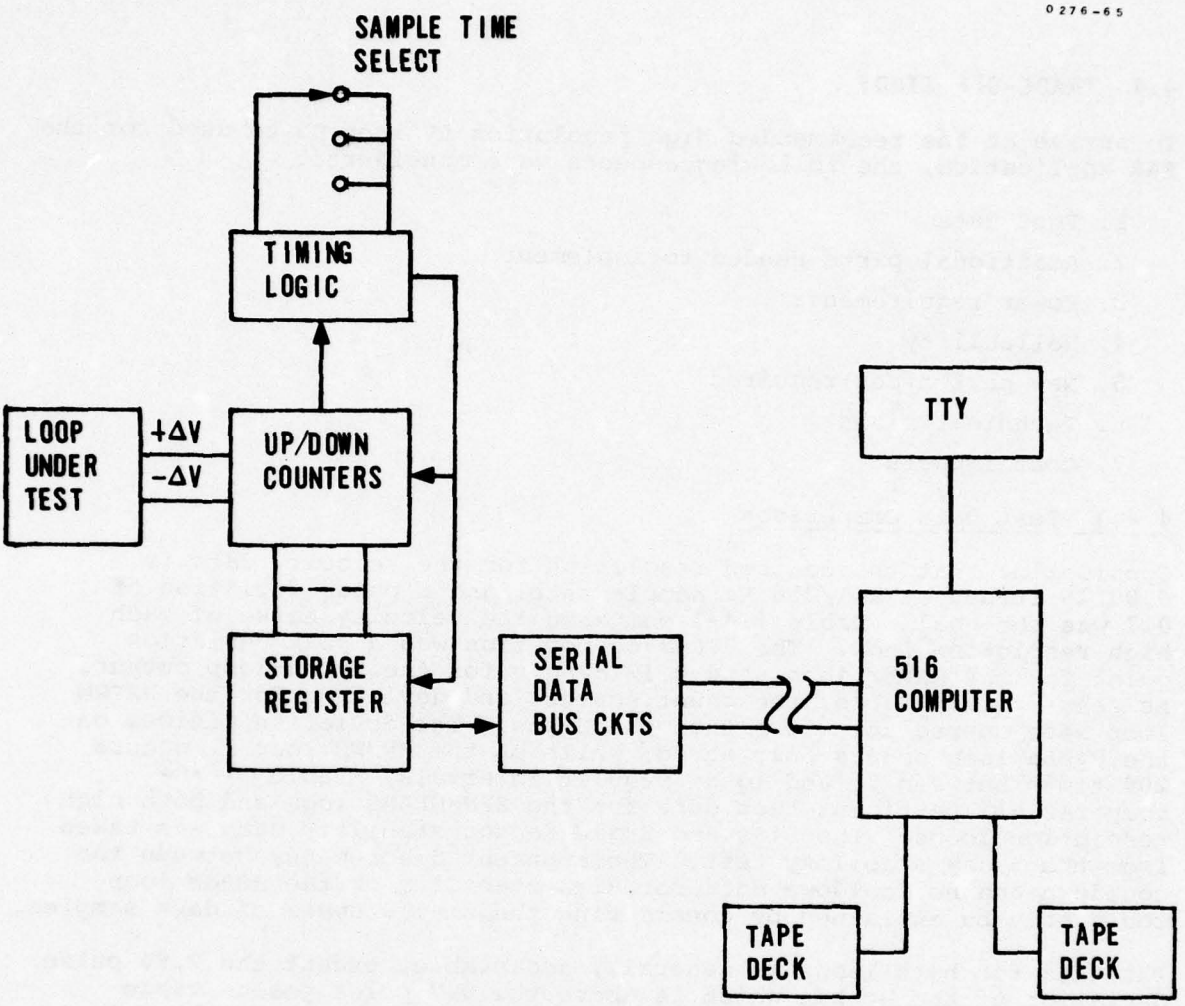


FIGURE 4.3-10. ACCELEROMETER DATA PROCESSING BLOCK DIAGRAM

4.4 TRADE-OFF STUDY

To arrive at the recommended high resolution ΔV loop to be used for the EAR application, the following aspects were considered.

1. Test data
2. Additional parts needed to implement
3. Power requirements
4. Reliability
5. New part types required
6. Technical risks
7. Cost impacts

4.4.1 Test Data Comparison

Considering that the desired resolution for the velocity data is 0.00125 ft/sec at a 1/256 Hz sample rate, and a pulse deviation of 0.7 was the goal, Table 4.4-1 compares the velocity noise of each high resolution loop. The 0.06976g position was a peak deviation point for the HRPWM loop, and 0.12187 g's for the Hypha loop output. As seen in this table, the count scatter and deviation for the HRPWM loop were appreciably less than the Hypha. The deviation minimum on the Hypha loop occurs only at 0g, while on the HRPWM loop it occurs 204 times between 0g and 1g at regular intervals. Table 4.4-2 compares all pertinent test data for the SPN/GEANS loop and both high resolution loops. The Bias and Scale Factor stability data was taken from the 5 day stability test. The apparent discrepancy between the cooldown and no cooldown data for Bias stability on the HRPWM loop could only be explained by considering the small number of data samples.

The data for both loops is generally acceptable, except the 0.96 pulse deviation of the Hypha, which is above the 0.7 pulse goal. Table 4.4-2 is a summary of the full linearity test data for all three loops. This table indicates basically identical operation considering it is comparing a single test result. Table 4.4-3 summarizes all key data. All in all, the data comparisons indicate that the HRPWM loop has a slight edge on the Hypha loop in performance.

4.4.2 Additional Parts Needed to Implement

A parts count of each method indicates that the Hypha loop mechanization will require approximately 223 parts. The HRPWM loop will require only 20 parts. These counts do not include those parts needed for the new data bus and other circuits needed for either method (see Table 4.4-4).

TABLE 4.4-1. VELOCITY NOISE SUMMARY
(1/256 second net count summary over a 4 second period)

	INPUT g's	HRPWM	HYPHA
COUNT SPREAD	0g	± 1	± 4
Pulses at 262,144 Hz	.06976	± 2	
	.12187		+4, -6
	1g	± 1.75	+4, -0
STD DEVIATION	0g	0.2	0.3
Pulses at 262,144 Hz	.06976	0.68	-
	.12187		.911
	1g	0.6	0.5

TABLE 4.4-2. ACCELEROMETER LOOP LINEARITY
SPN - MOD SPN - HYPHA

PARAMETER	Value (μg)		HRPWM
	SPN	HYPHA	
PEAK DEVIATION FROM A LINE	-48	-52	-51.4
MEAN DEVIATION FROM A LINE	-19.3	-22.8	-16.8
RMS DEVIATION FROM THE MEAN DEVIATION FROM A LINE	15.6	15.9	23.6
RMS OF THE DEVIATIONS FROM A LINE	24.8	27.8	29.0
1 g BIAS	-530	-526	-517
0 g BIAS	-578	-578	-543
Δ (1g $\rightarrow$ 0g) BIAS	- 48	- 52	- 26

TABLE 4.4-3. ACCELEROMETER LOOP PERFORMANCE
SUMMARY
SPN - HRPWM - HYPHA

PARAMETER	COND.	SPN	HYPHA	HRPWM
VELOCITY NOISE:	MIN.	-	0.2	0.2
EQUIV STD. DEV. IN PULSES	MAX.	-	0.96	0.65
AT 262,144 Hz	AVG.	-	0.5	0.35
1g BIAS STABILITY (μg)	CD	5.9	20.5	21.1
r.m.s.	NCD	1.1	10.1	21.6
1g SCALE FACTOR STABILITY (ppm)	CD	8.5	13.3	5.7
r.m.s.	NCD	8.4	7.9	9.9
LINEARITY: STD. DEVIATION (μg) FROM A LINE		-19.3	-22.8	-16.8
THRESHOLD (sec)	MAX	2	< .5	< .5

TABLE 4.4-4. COMPARISON TABLE HYPHA VERSUS HRPWM

	HYPHA	HRPWM
ADDITIONAL PARTS	$\approx$ 223	$\approx$ 20
ADDED POWER REQUIRED	+5V: 1.5A $\pm$15V: .14A	+5V: $\approx$.13A
RISKS AND/OR COST IMPACT	CROSSTALK TUNING POWER IMU BALANCE NEW PARTS QUALIFICATION NEW HYBRID	CROSSTALK NEW HYBRID

4.4.3 Power Requirements

It is estimated that the Hypha interpolator would require 1.5 amps of +5 volts current, and 0.14 amps of ±15 volts current. The HRPWM loop mechanization would add 0.13 amps of +5 volts current. Again, these figures do not include power needed for other new circuits common to both methods.

4.4.4 Reliability

The impact on system reliability for each method would be directly related to the parts count and added power needs. The lower parts count and power consumption for the HRPWM loop indicates that it would be more reliable.

4.4.5 New Part Types Required

The Hypha loop mechanization would require the use of at least two parts which are not presently approved for SPN/GEANS. One is a 10 bit D/A and the other is the loop VCO. No new part types would be required for the HRPWM loop. Either method will require a new hybrid containing the demod, amplifier/filter and the comparator. This is required to provide VMU board space for the new circuits (see Figures 4.4-1 and 4.4-2).

4.4.6 Technical Risks

The risks to be considered with the Hypha Interpolator are as follows:

1. There is a possibility that noise and cross-talk could occur between the three loops. Such problems are common in this type of circuit.

2. Tuning and lock-on are necessary aspects of Phase lock loops. Much care has to be exercised in assembly and test.

3. The Pendulum amplifier gain and filtering may have to be individually tuned to a particular accelerometer loop. This complicates testing and will "marry" a particular Hypha circuit board to a particular VMU.

4. The larger volume of board space required in the IMU logic board area to house the Hypha could cause problems of balance, symmetry and thermal characteristics.

5. Carrying the low level Demod signal through the slip rings could be risky.

The technical risks involved in the HRPWM loop are as follows:

1. There is a possibility that problems would be encountered in noise and cross-talk when the new loops are packaged on the VMU. These risks are no more than normally expected when a new circuit is packaged.

2. Some element of risk is involved in transmitting higher ΔV frequencies through the slip rings, which is the most likely method considered. The results of slip ring transmission tests performed as part of this program, however, indicate that this problem can be minimized (see Section 5).

4.4.7 Cost Impact

In studying the cost impact of the two methods, the following aspects were considered:

1. Assemblies affected
2. Parts required
3. Testing and assembly time.

4.4.7.1 HRPWM

This modification will require modifying PRE boards No. 2 and No. 1A and redesigning board 1B to make room for new components. Some components will be required on a new circuit board in the IMU logic board area but they may fit onto the new board needed for the EAR data bus. The ΔV output board in the IMU logic section will need modification.

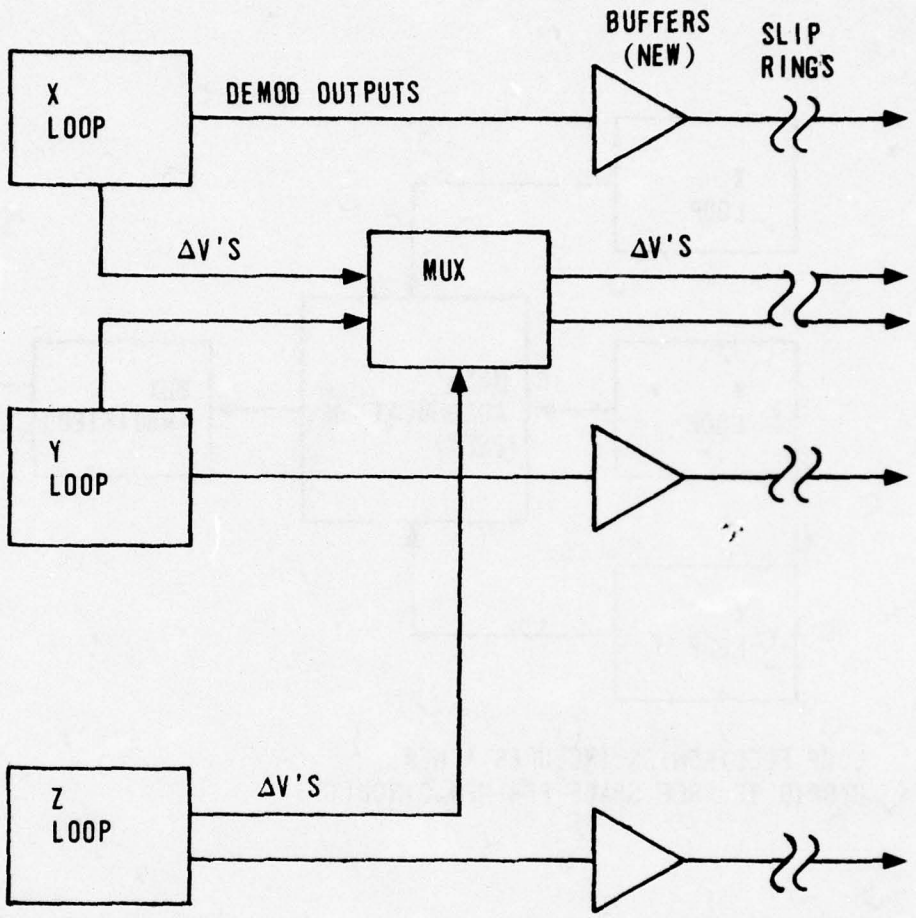
The new parts required for this method are not new to the program and will number approximately 20. No special tuning or parts selection will be required above that now done for a SPN/GEANS VMU. No increase in assembly time is anticipated.

4.4.7.2 Hypha Interpolator

The incorporation of the Hypha Interpolator modification will require:

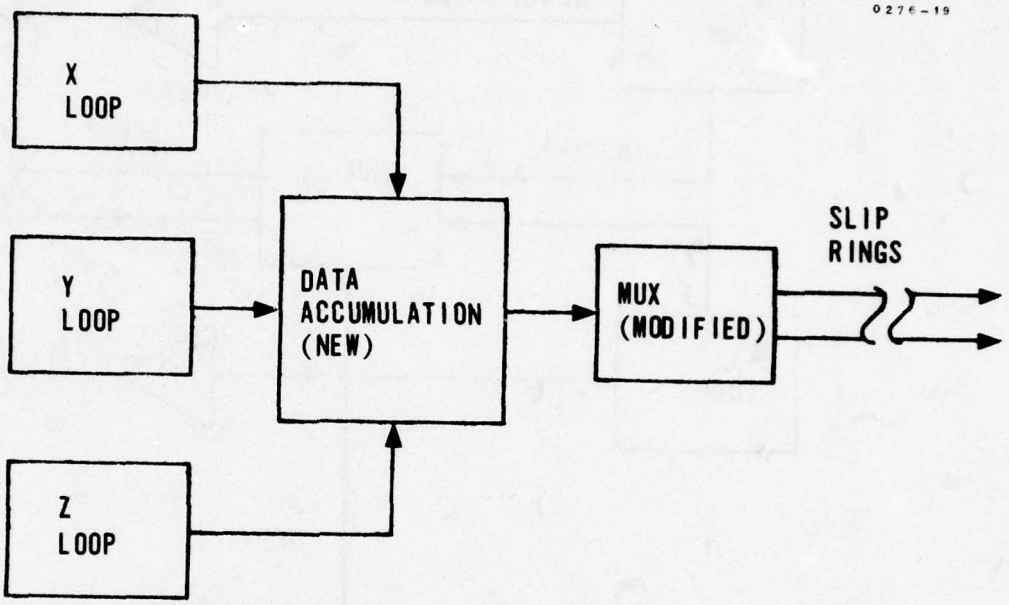
1. Redesign and build PRE board 1B in the VMU.
2. Design and build two new circuit boards for the Hypha circuitry in the IMU logic section.
3. Modify the ΔV output data board in the IMU.
4. Pick up three new slip rings in the IMU wiring.

The parts required for this method will number approximately 223 with two types requiring qualification. The extra tuning and parts selection needed here would also incur added expense.



NOTE: LOOP ELECTRONICS INCLUDES
A NEW HYBRID TO FREE SPACE
FOR BUFFERS

FIGURE 4.4-1. VMU MODS NEEDED FOR HYPHA



NOTE: LOOP ELECTRONICS INCLUDES A NEW HYBRID TO FREE SPACE FOR NEW CIRCUITS

FIGURE 4.4-2. VMU MODS NEEDED FOR HRPWM

Section 5

INCREASED ΔV/GIMBAL ANGLE SAMPLE RATE

5.1 TECHNICAL CIRCUIT DESCRIPTION

Six different concepts of how to decode, count and transmit ΔV's for EAR application to a SPN/GEANS system were presented at the Preliminary Design Review.

Two of the six concepts were chosen for study. One concept pertains to the Hypha Interpolator (H/I) loop, the other to the High Resolution Pulse Width Modulator (HRPWM) loop. The PDR set the effective quantization for the H/I loop at 0.00125 ft/sec/pulse and 0.00250 for the HRPWM loop. The high data interrupt rate was changed from 128 Hz to 256 Hz. These changes were incorporated into the ΔV readout design. Later inputs set the requirements at 0.00125 ft/sec for either method.

For gimbal angle readout the SPN/GEANS system utilizes a phase locked loop resolver-to-digital converter which converts the angle at a 512 Hz rate. The converted angle is stored in the serial output registers and is, therefore, available by requesting it via the serial data bus at any binary increment less than or equal to a 512 Hz rate. Since 256 Hz falls into this area, no hardware changes are required for the increased gimbal angle readout rate.

5.1.1 The High Resolution Pulse Width Modulator ΔV Readout Circuit Design

Two methods are presently being considered for gathering and transmitting this data.

5.1.1.1 Method A

The ΔV data will be accumulated in up/down counters at a 8192 Hz rate in the VMU. Both + and - sums will be accumulated and multiplexed together for transmittal through the slip rings. In the IMU logic area a decoder will separate the three channels of ΔV data. A set of adders will accumulate 32 sums of data to obtain 256 Hz data. This data will then be transmitted to the EAR computer via a separate serial data bus. The 256 Hz data will also be accumulated and added to obtain 32 Hz data. This data will be transmitted to the navigation computer. See Figure 5.1-1.

5.1.1.2 Method B

The other method being considered is to multiplex the raw ΔV data and transmit the high frequency data directly through the slip rings. The data would then be decoded, counted and transmitted to each computer as required. See Figure 5.1-2.

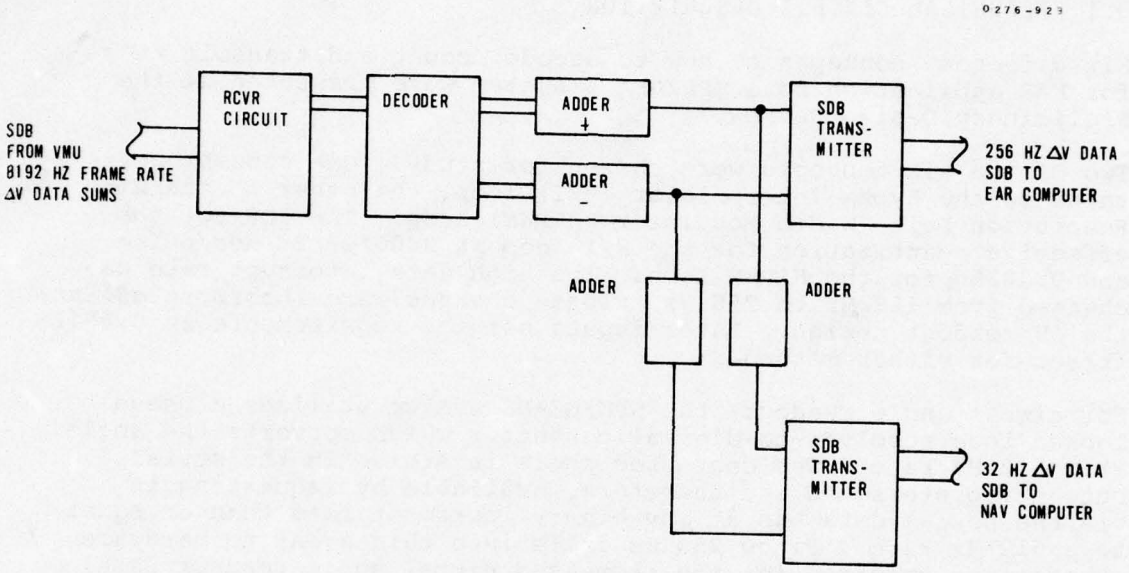


FIGURE 5.1-1. METHOD A HRPWM ΔV DATA SYSTEM

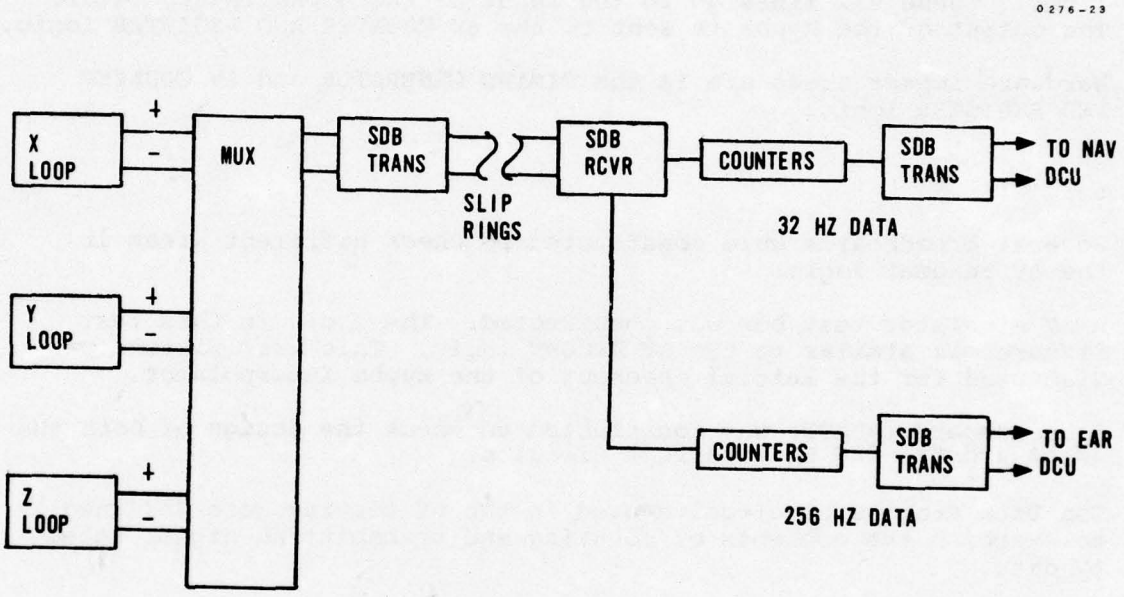


FIGURE 5.1-2. METHOD B HRPWM ΔV DATA METHOD

5.1.2 The Hypha Interpolator ΔV Readout Design

(Refer to Block Diagram Figure 5.1-2 and Schematic Figure 5.1-3) The ΔV decoding logic receives raw multiplexed tri-level ΔV's from the Velocity Measuring Unit (VMU) at a 8192 Hz frame rate. The ΔV's are decoded into separate + X, Y & Z and - X, Y & Z data lines. These six lines go to the input of the Hypha Interpolator. The output of the Hypha is sent to the ΔV COUNTER AND REGISTER logic.

Hardware impact areas are in the TIMING GENERATOR and ΔV COUNTER AND REGISTER logic.

5.2 STATUS

Several breadboards were constructed to check different areas in the ΔV readout logic.

A ΔV simulator test box was constructed. The logic in this test fixture was similar to the ΔV DECODE logic. This test fixture was also used for the initial checkout of the Hypha Interpolator.

A breadboard (AUGUT) was constructed to check the design of both the 32 Hz and the 256 Hz interrupt circuits.

The Data Processing circuits used in the ΔV testing were designed to exercise the concepts of counting and transmitting higher speed ΔV data.

An IMU slip ring noise test was performed and is reported upon in Paragraph 5.3.1.

5.3 BRASSBOARD TEST RESULTS

The Data Processing hardware used in ΔV data collection effectively verified that high speed ΔV data could be counted and transmitted sucessfully. ΔV data at a 262,144 Hz rate was successfully collected and processed at rates as high as 2048 Hz.

The slip ring transmission test and test results are discussed in the following paragraphs.

5.3.1 Slip Ring Transmission Test

The object of performing these tests was to determine how much noise, if any, would be radiated into surrounding signal lines when high frequency, fast rise time signals are transmitted through slip rings in an inertial platform (IMU).

Three tests were performed. Tests I and II were run on an actual IMU. Test III used a single slip ring capsule. A summary of these tests is contained in the following paragraphs.

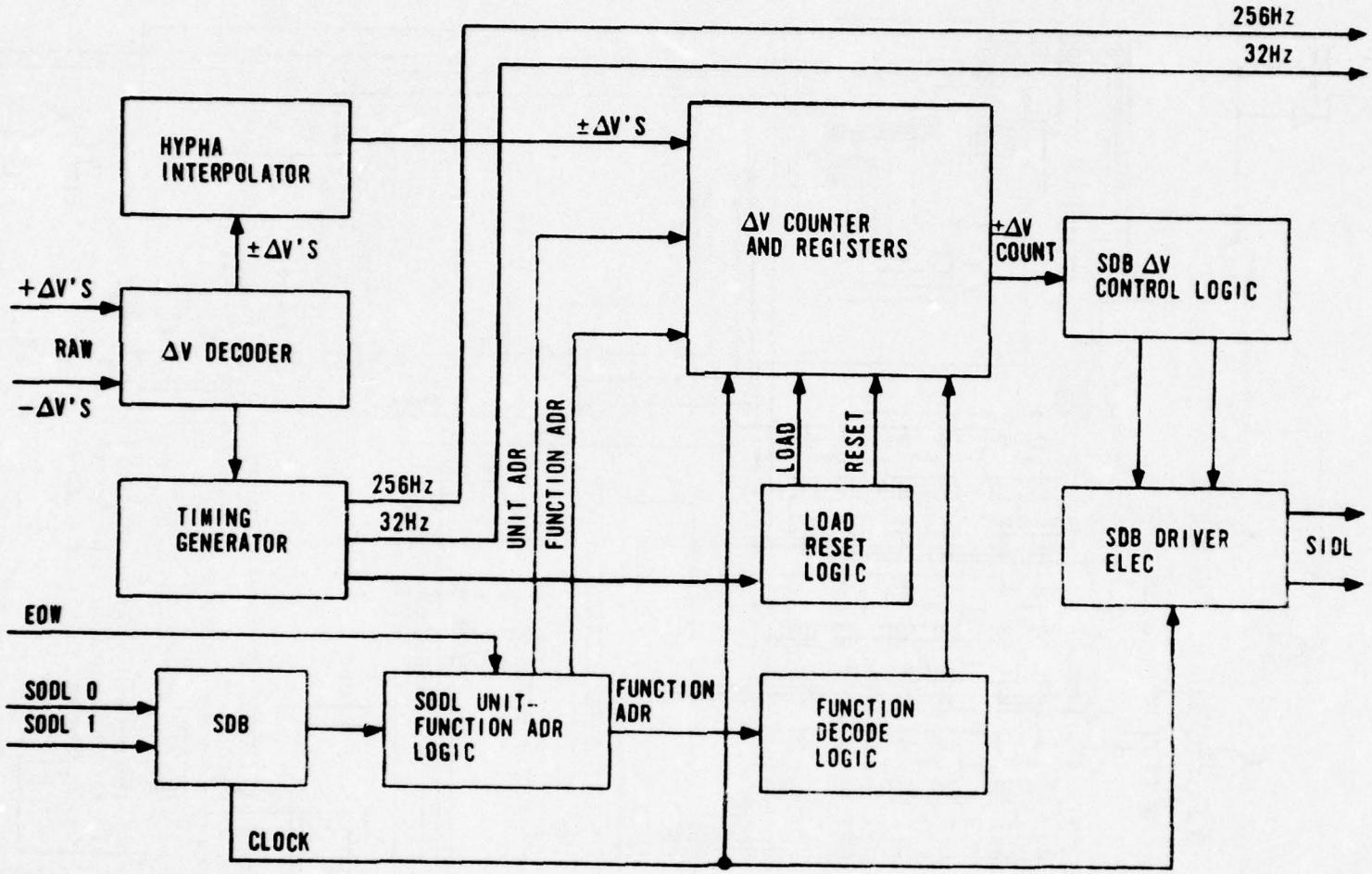


FIGURE 5.1-3. ΔV READOUT BLOCK DIAGRAM FOR HYPHA INTERPOLATOR CONCEPT

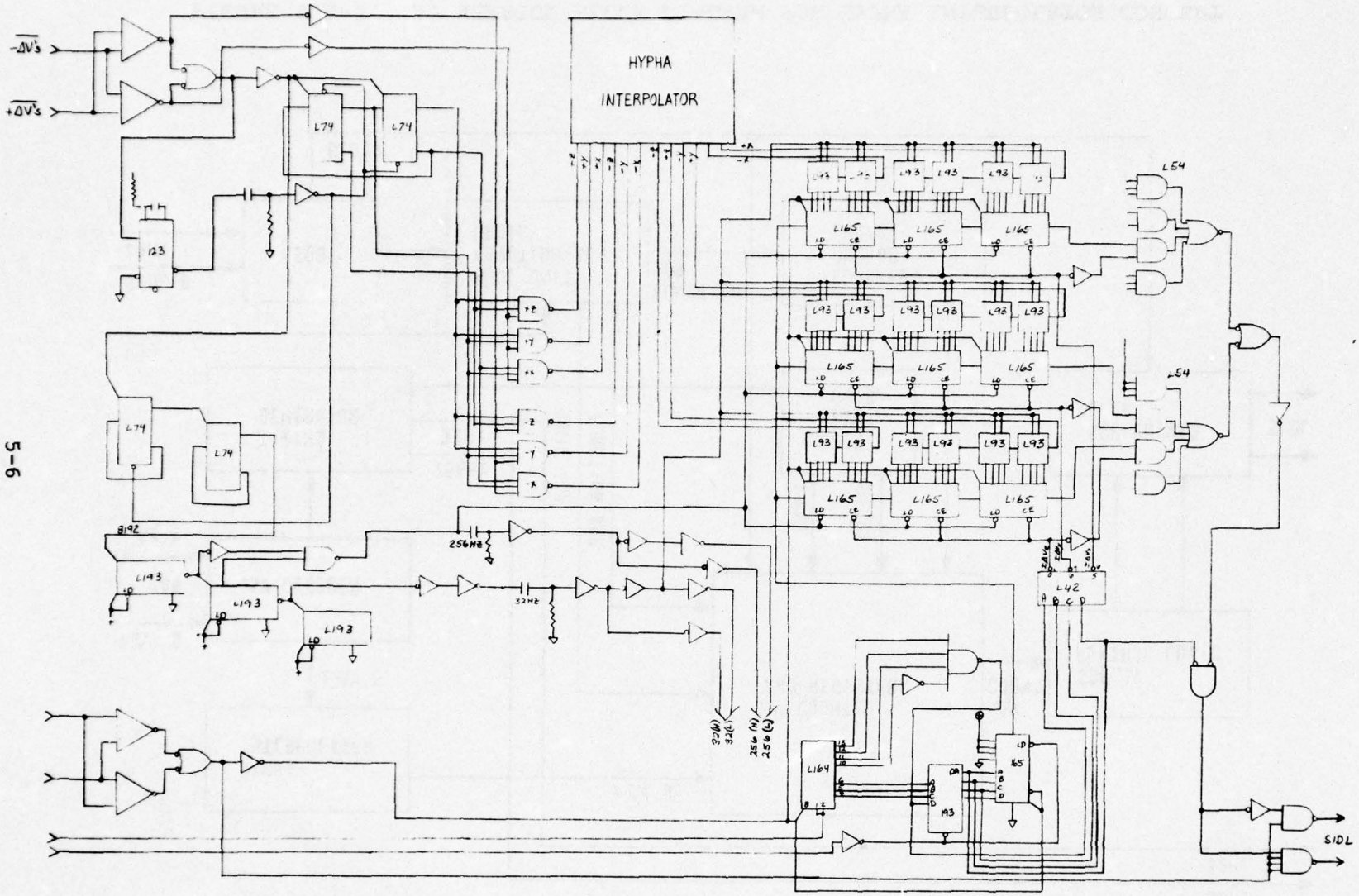


FIGURE 5.1-4. ΔV READOUT CIRCUIT DESIGN FOR HYPHA INTERPOLATOR CONCEPT

5.3.1.1 Test I

The object of this test was to determine what slip ring lines or pairs were more susceptible to radiated noise with respect to their proximity to the radiated source.

The test conditions are as follows:

1. High frequency source was a 1 MHz square wave.
2. Test was run on an IMU.
3. Four pairs of slip ring lines which ran from axis one to axis four were used for the test.
4. Simulated load resistance of 10KΩ and source resistance of 100Ω were used on monitored test lines.
5. The high frequency signal was transmitted through several combinations of the four slip ring pairs.

Figure 5.3-1 shows the best path and Figure 5.3-2 shows the worst path combinations that were tested.

5.3.1.2 Test II

The object of this test was also to determine what slip ring lines or pairs were more susceptible to radiated noise with respect to their proximity to the radiated source.

This test was the same as Test I except the high frequency source was changed from a square wave to a tri-level signal which simulated the ΔV data rate needed if the High Resolution Pulse Width Modulator loop were used.

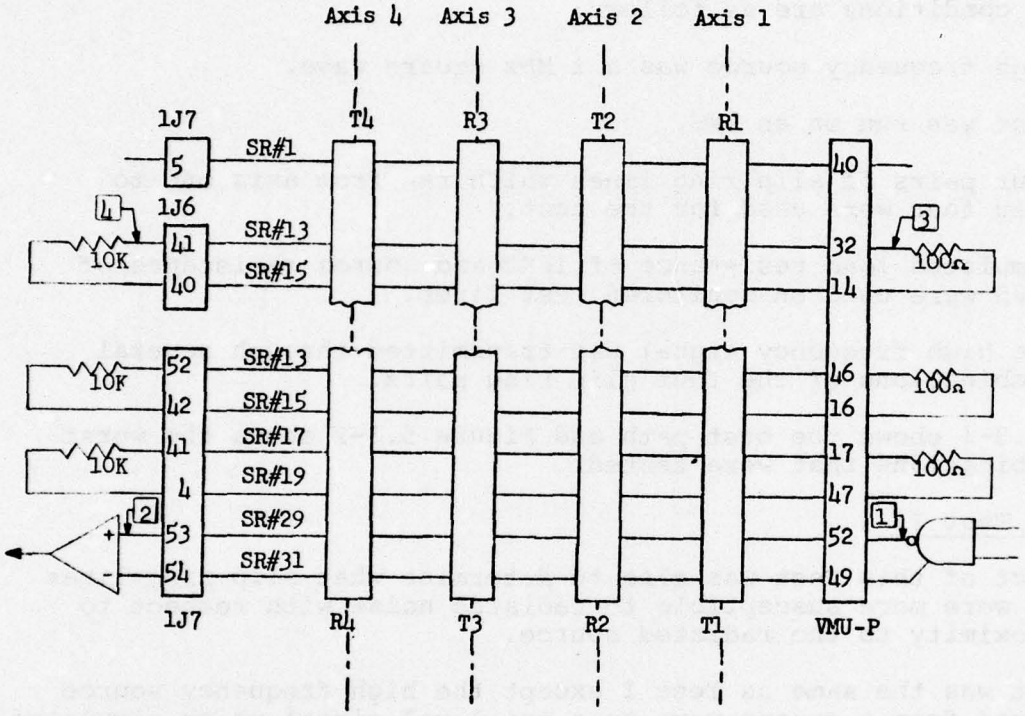
Figure 5.3-3 shows the best path combination and Figure 5.3-4 shows the worst path combination of all the combinations tested.

5.3.1.3 Test III

The object of this test was to see how radiated noise can be reduced on susceptible signal lines which share the same slip ring capsule.

The test was performed using a single slip ring capsule. The high frequency signal was tri-level at the HRPWM data rate. Four test combinations were tried:

1. Twist all unused odd slip rings in pairs.
2. Ground all unused slip rings.
3. Ground slip ring capsule.
4. Added 470 pf across 10K load resistor on monitored lines.





Trace #1 at Location [1]
Vert = 5V/CM

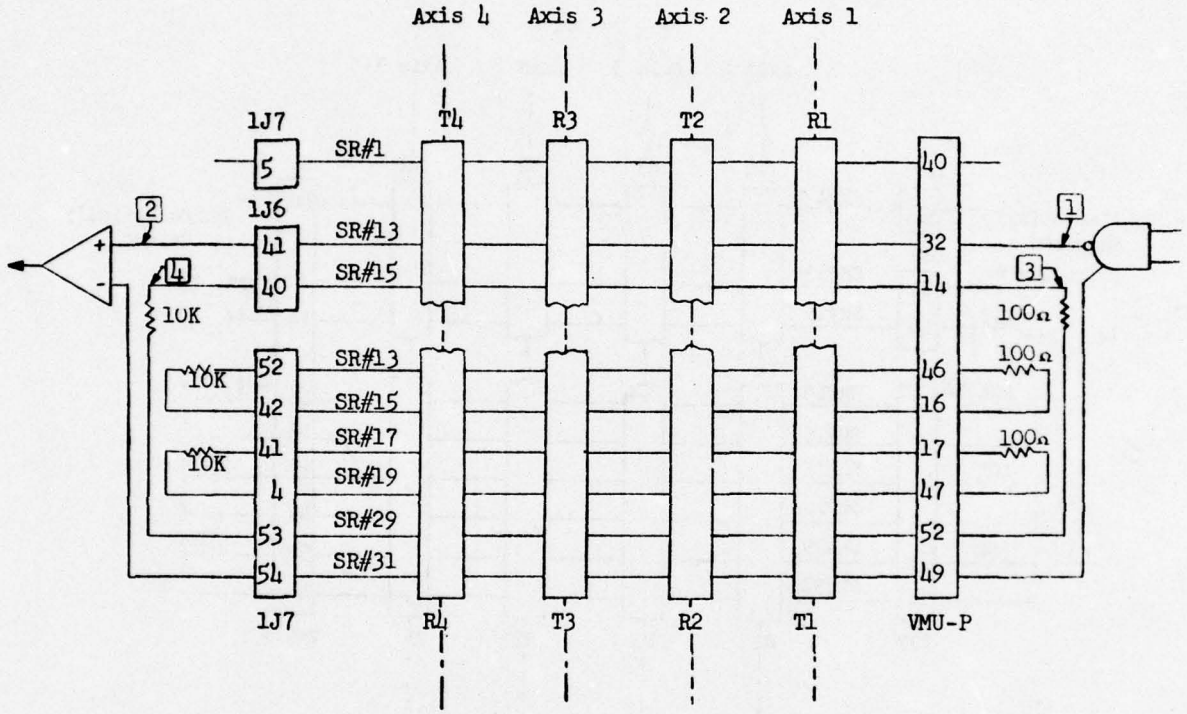
Trace #2 at Location [2]
Vert = 5V/CM

Trace #3 at Location [3]
Vert = 0.5V/CM

Trace #4 at Location [4]
Vert = 0.5V/CM

Horiz = 0.5us/CM

FIGURE 5.3-1. SLIP RING TEST I





Trace #1 at Location [1]
Vert = 5V/CM

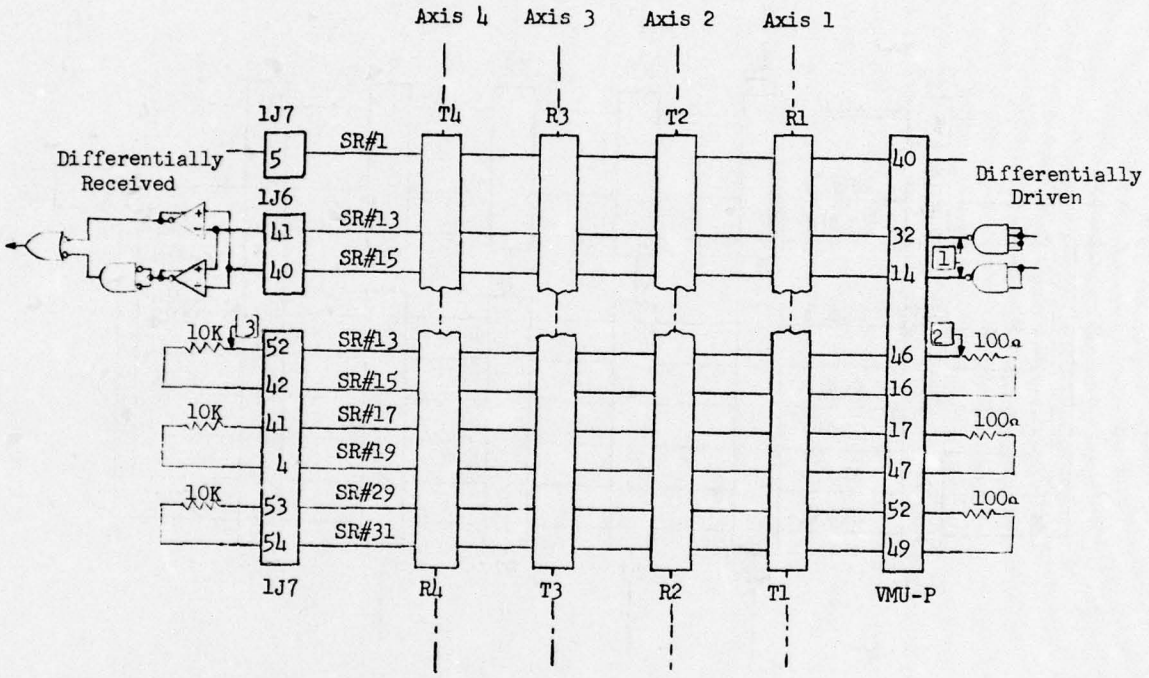
Trace #2 at Location [2]
Vert = 5V/CM

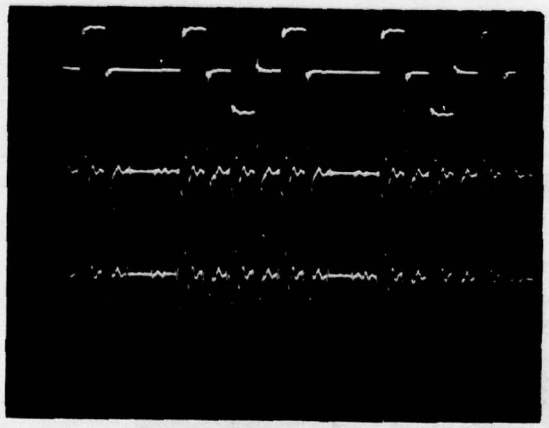
Trace #3 at Location [3]
Vert = 2V/CM

Trace #4 at Location [4]
Vert = 2V/CM

Horiz. = 0.5us/CM

FIGURE 5.3-2. SLIP RING TEST I





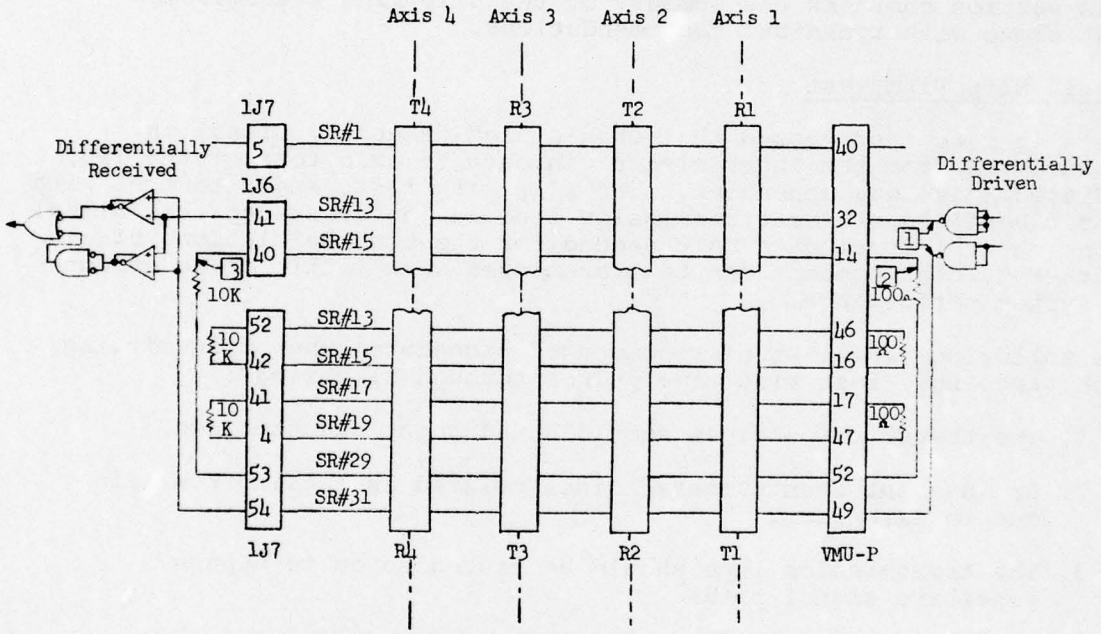
Trace #1 Location [1]
Vert = 5V/CM

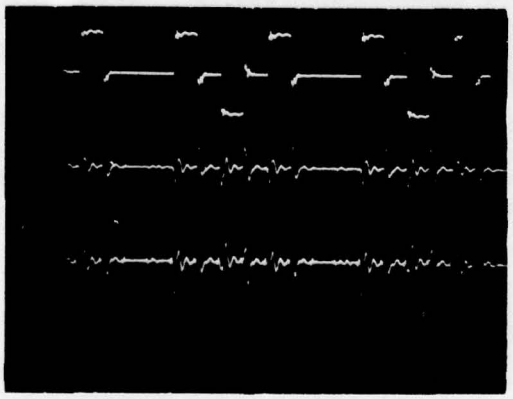
Trace #2 Location [2]
Vert = 1V/CM

Trace #3 Location [3]
Vert = 1V/CM

Horiz = 1us/CM

FIGURE 5.3-3. SLIP RING TEST II





Trace #1 Location [1]
Vert = 5V/CM

Trace #2 Location [2]
Vert = 2V/CM

Trace #3 Location [3]
Vert = 2V/CM

Horiz. = lus/CM

FIGURE 5.3-4. SLIP RING TEST II

Test I had no noticeable affect on noise reduction. Test II and III did reduce noise. Test IV reduced the noise significantly.

Figure 5.3-5 shows the signal noise before and Figure 5.3-6 shows the signal noise after implementation of tests I, II, III and IV.

5.4 SUMMARY AND TECHNICAL RECOMMENDATIONS

This section contains the summary of the slip ring transmission test along with technical recommendations.

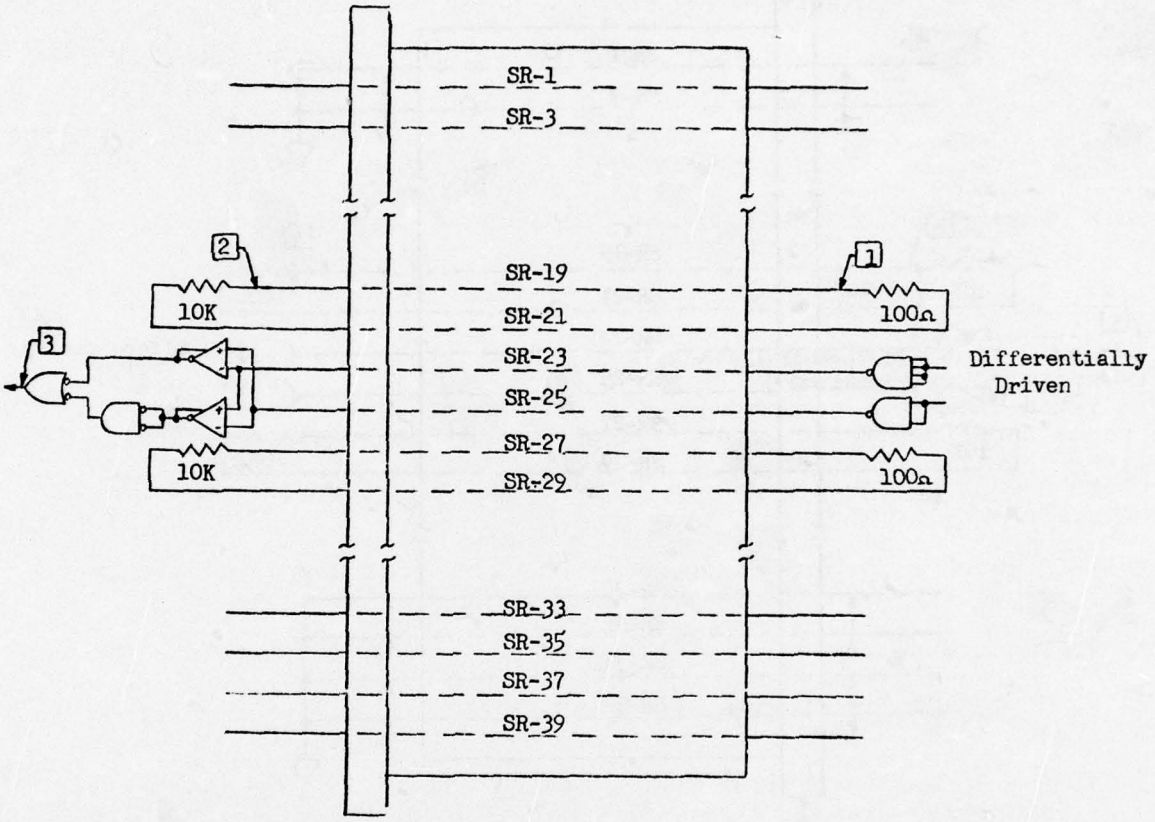
5.4.1 Slip Ring Test

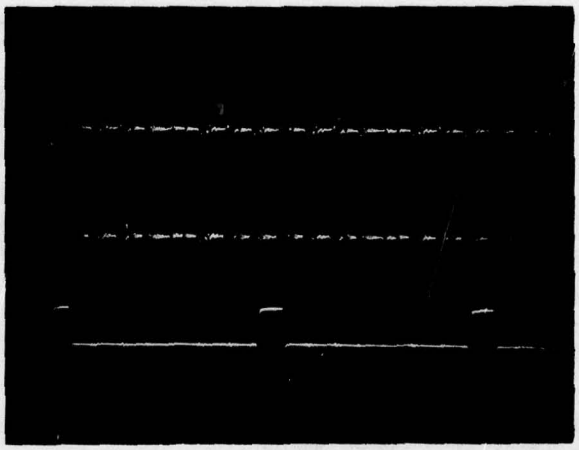
The slip ring test showed that when a high frequency signal is transmitted from the inner element through to axis four of the IMU, radiated noise was generated. The slip ring tests indicate that with proper handling of the transmission line and noise susceptible signal lines the tri-level data rate needed for the High Resolution Pulse Width Modulator concept can be transmitted with little or no effect on system performance.

The following is a list of recommended procedures when transmitting high frequency, fast rise time pulses through slip rings:

1. The transmission lines should be adjacent odd numbered
2. Or adjacent even numbered lines twisted as a pair from axis one to axis four.
3. The transmission line should be routed so as to bypass sensitive signal paths.
4. All unused slip ring wires should be terminated to ground.
5. All slip ring capsules should be grounded.
6. The addition of a small value capacitor across the input of a susceptible component to reduce the noise.

As presented in this report, the ΔV readout for the H/I will transmit a minimum of 13 bits of + ΔV's and 8 bits of - ΔV's. With a new counter/register hybrid design, this could be increased up to 11 bits of - ΔV's. This would assure a better reasonableness check on the $\pm$ ΔV's.





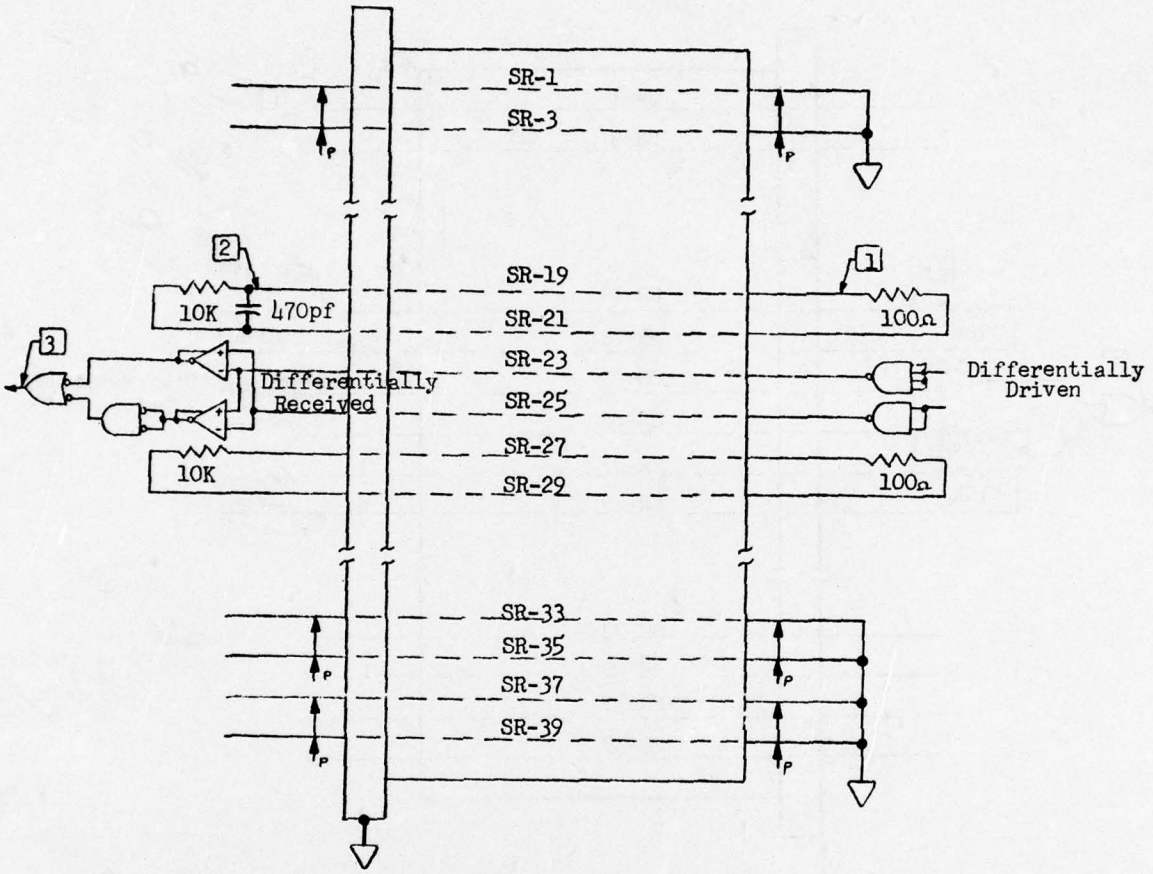
Trace #1 Location [1]
Vert = 0.5V/CM

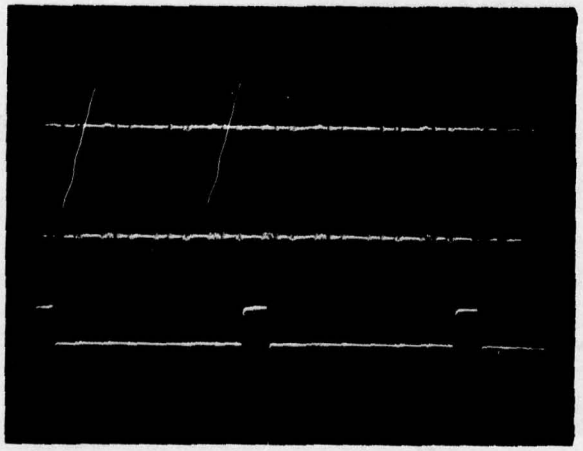
Trace #2 Location [2]
Vert = 0.5V/CM

Trace #3 Test Pattern [3]
Vert = 5V/CM

Horiz. = 1 us/CM

FIGURE 5.3-5. SLIP RING TEST III





Trace #1 Location [1]
Vert = 0.5V/CM

Trace #2 Location [2]
Vert = 0.5V/CM

Trace #3 Test Pattern [3]
Vert=5V/CM

Horiz. = lus/CM

FIGURE 5.3-6. SLIP RING TEST III

Section 6

EARS SYSTEM TESTS

System level vibration testing was performed from 6 September 1974 through 17 September 1974 using an optimized AN/ASN-101 GEANS in the environmental laboratory, building E1, of the Development and Evaluation department of the Aerospace Division of Honeywell Inc. at St. Petersburg, Florida. The purpose of these tests was primarily to determine the transmissibility of the IMU using different sets of vibration isolators. The vibration inputs for the sine are shown in Figures 6-1 and 6-2, and the random in Figure 6-3.

Detail plots of the twelve seismic accelerometers instrumenting the IMU have been compiled and analyzed. Figure 6-4 gives a diagram of the placement of the accelerometers and their respective sensing axes.

A secondary purpose was to determine the repeatability of each set of isolators before and after each vibration in all three axes. The method of obtaining this data is described in Subsection 6.1 and the results are summarized in Table 6.3-1.

Another aspect of interest was the maximum sway of the IMU. These measurements were only partially successful. The technique used to obtain the data is described in Subsection 6.3 and the results are summarized in Table 6.3-2.

Subsection 6.3 contains the analysis of vibration test results.

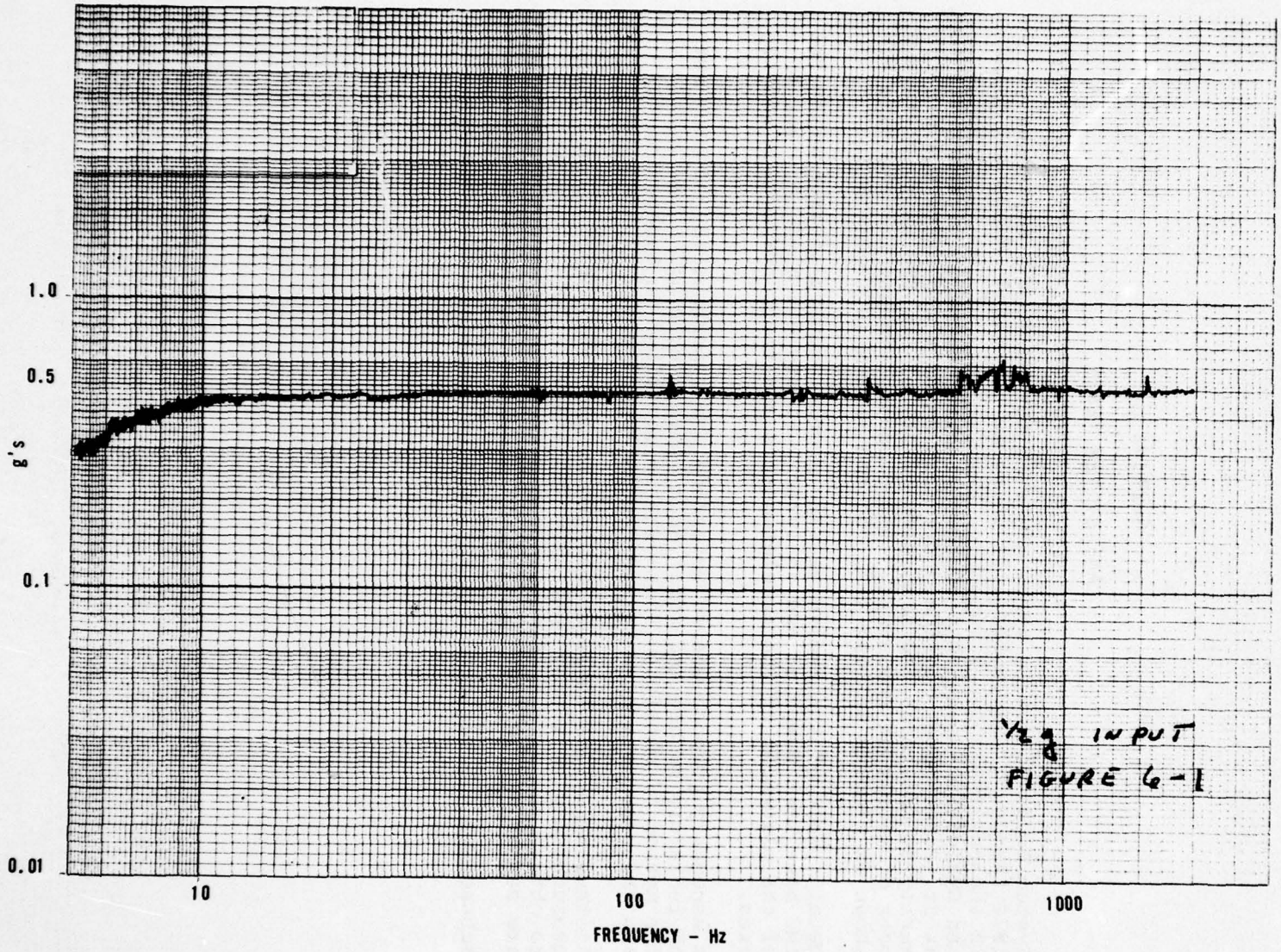


FIGURE 6-1. 1/2 g INPUT

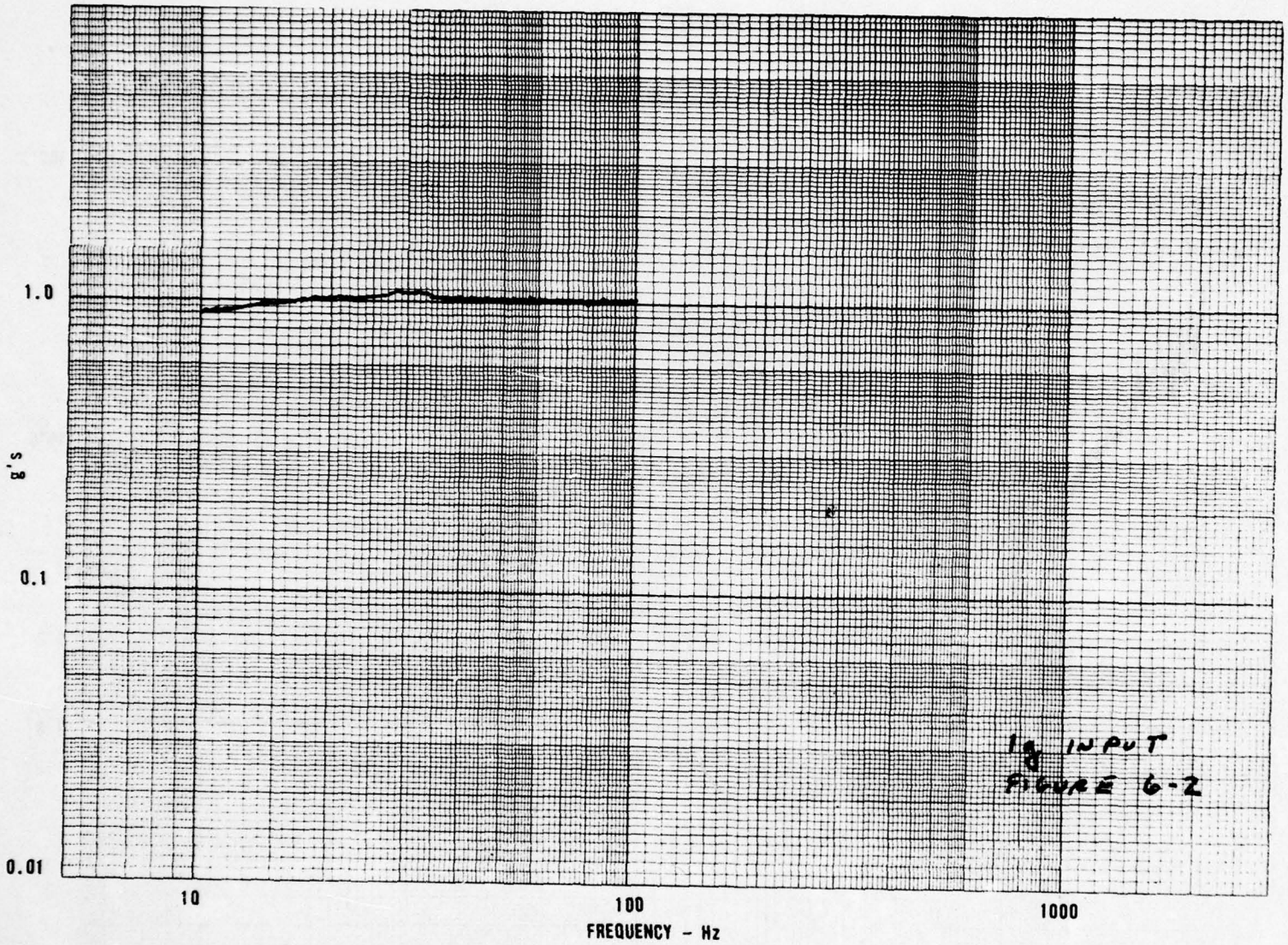


FIGURE 6-2. 1 g INPUT

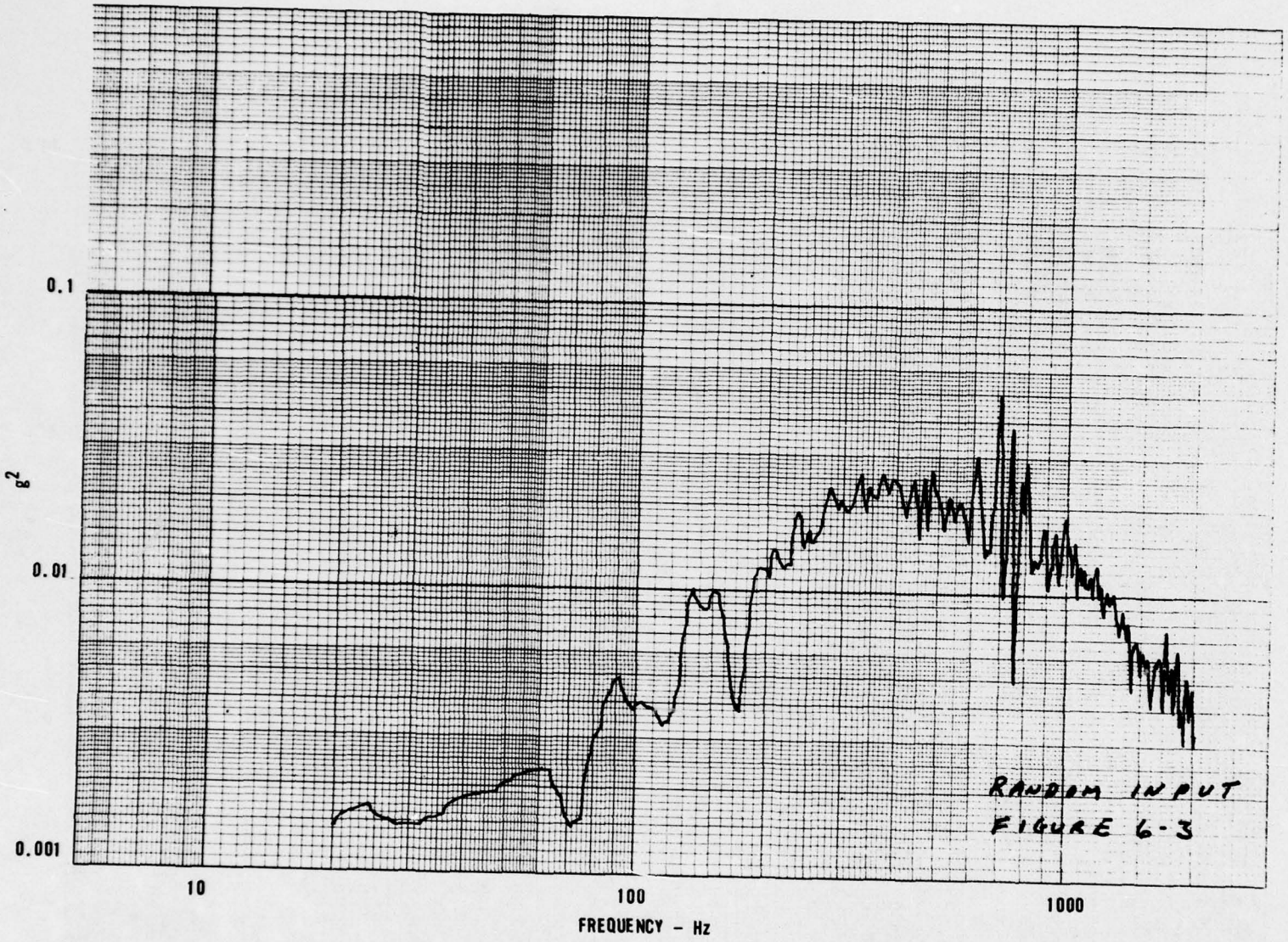


FIGURE 6-3. RANDOM INPUT

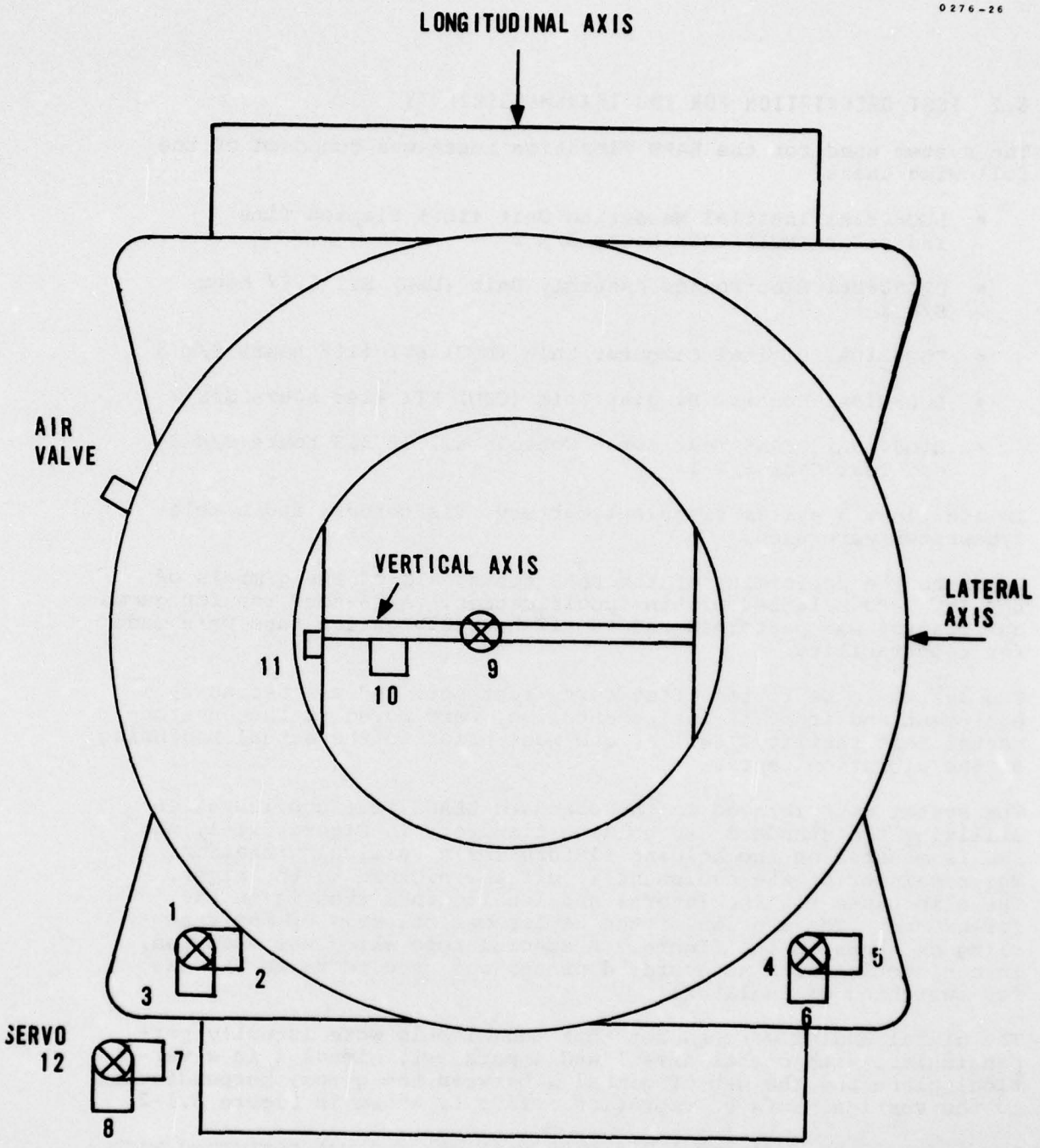


FIGURE 6-4. ACCELEROMETER PLACEMENT AND AXIS INDICATION

6.1 TEST DESCRIPTION FOR IMU TRANSMISSIBILITY

The system used for the EARS vibration tests was composed of the following units:

- DGG8091A1 Inertial Measuring Unit (IMU) Elapsed Time Indicator (ETI) 1009 hours S/N 2
- DEG808261 Electronics Assembly Unit (EAU) ETI 5787 hours S/N 1
- DBG8210A1 Digital Computer Unit (DCU) ETI 4187 hours S/N 3
- DCG8019A1 Control Display Unit (CDU) ETI 4045 hours S/N 3
- DUG8419A1 GEANS Test Set - Console ETI 12,363 hours S/N 3 and Test Cart S/N 1

In addition, a system transient battery, Visicorder, and a teletypewriter were used.

Prior to the performing of the EARS tests, all of the gimbals of the IMU were balanced within specification. A 36-hour run for gamma calibration was performed and two 12-hour navigation runs were made for repeatability.

The system to be tested, test cart, test set, and all necessary equipment and items of instrumentation, were moved to the environmental test facility, Cell A, one week prior to the actual beginning of the vibration tests.

The system was vibrated in the standard GEANS test configuration utilizing the standard IMU holding fixture. In Figure 6.1-1, the IMU is mounted on the holding fixture for a vertical vibration. The remainder of the equipment is off the picture to the right. The slip plate for the lateral and longitudinal axes is in the foreground. The tension of the cables was relieved by the rope sling as shown in the figure. A special rope sling was made and, in conjunction with an overhead crane, was used to raise the IMU for switching of isolators.

The gimbal angles were so set that the gimbals were mutually perpendicular, with gimbal axes 1 and 4 parallel, gimbal 4 in a vertical plane and the web of gimbal 1 between the gyros, perpendicular to the vertical axis of vibration. This is shown in Figure 6.1-2.

A special 16 Hz isolator 1/2 g sine vertical run was performed with the first and fourth gimbals counter-rotated 45 degrees as shown in Figure 6.1-3.

Figure 6.1-4 shows the three accelerometers attached to the inner element. They are mounted as close as possible to the gyro mounting feet to insure that they accurately determine the vibration levels

A7409-102

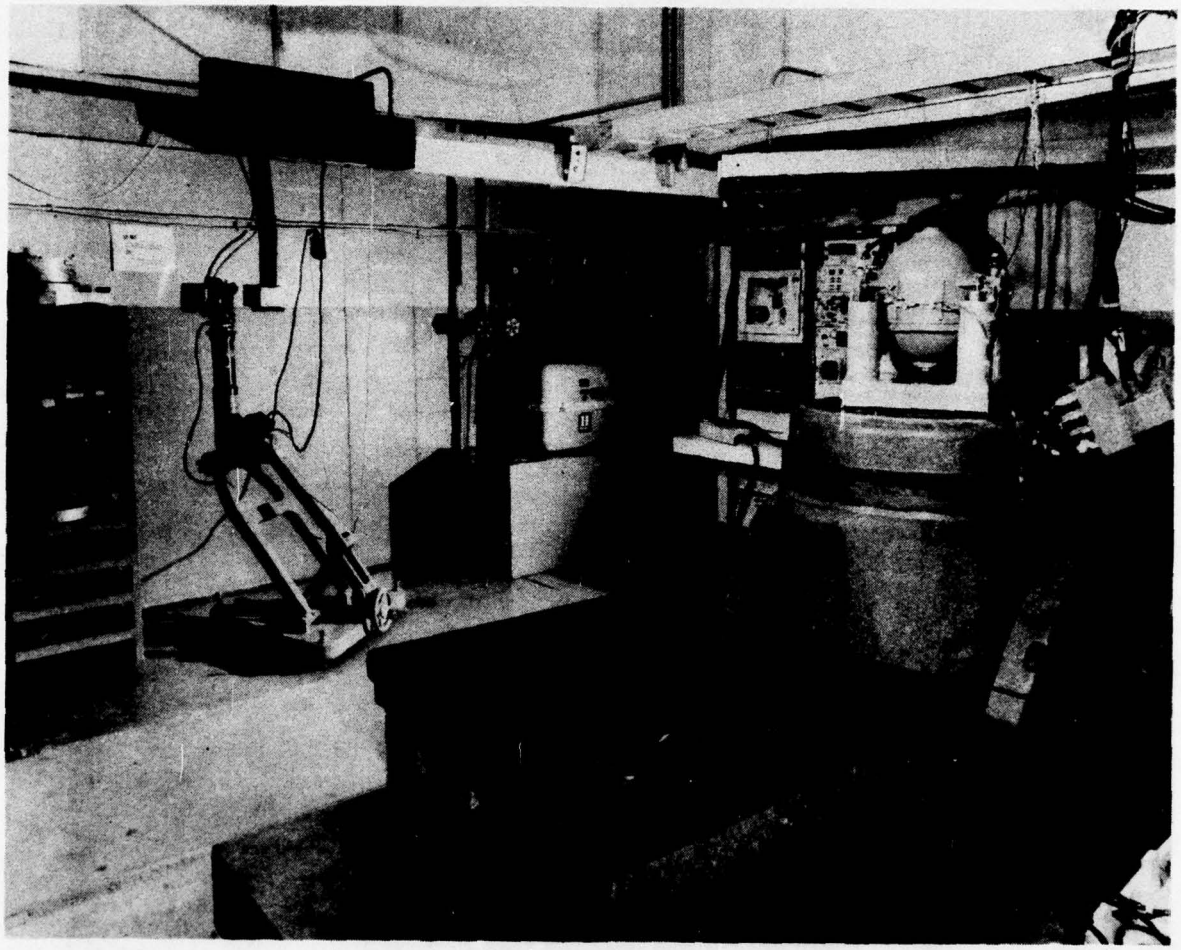


FIGURE 6.1-1. GEANS ON HOLDING FIXTURE FOR VERTICAL VIBRATION

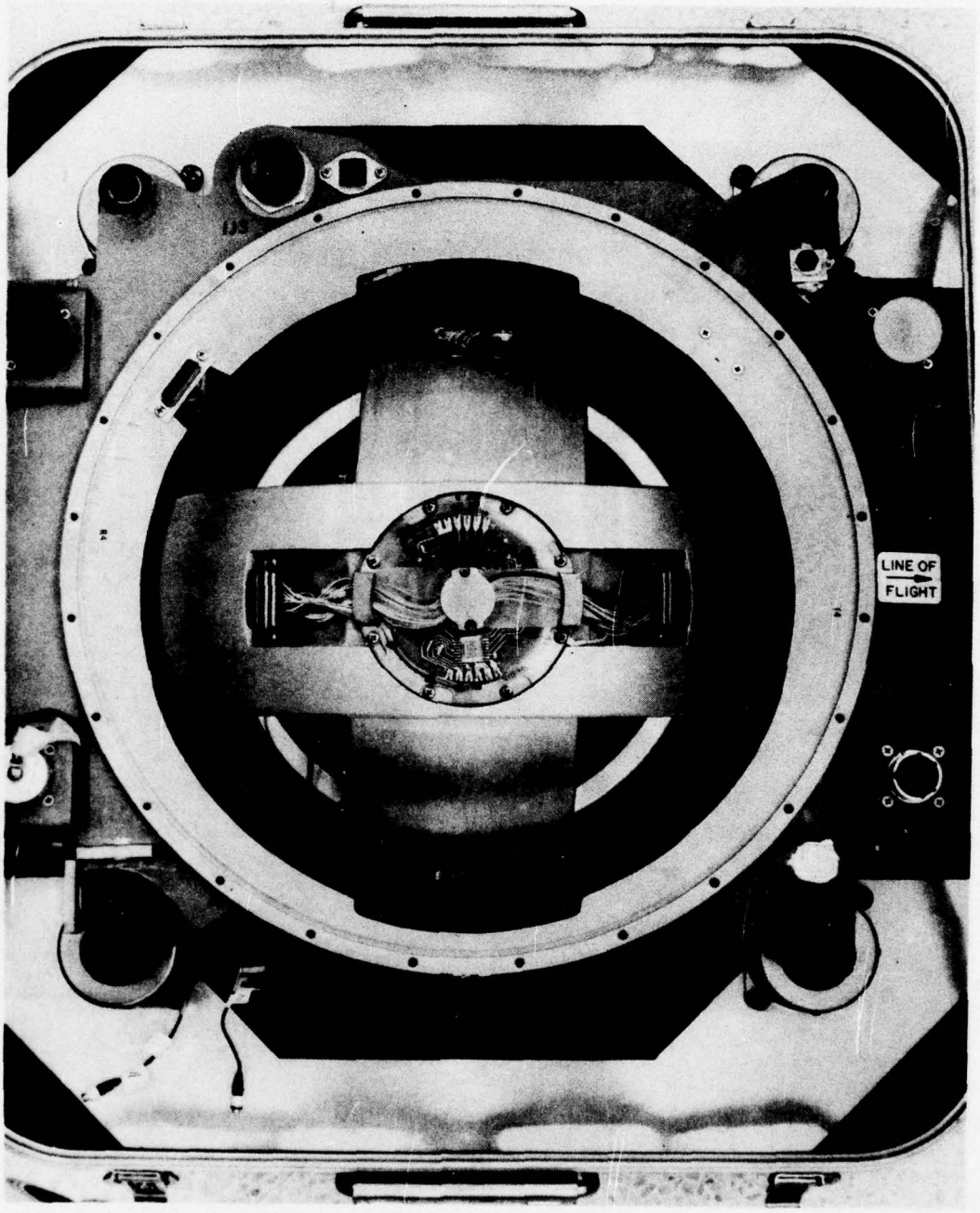


FIGURE 6.1-2. ORTHOGONAL GIMBAL POSITION

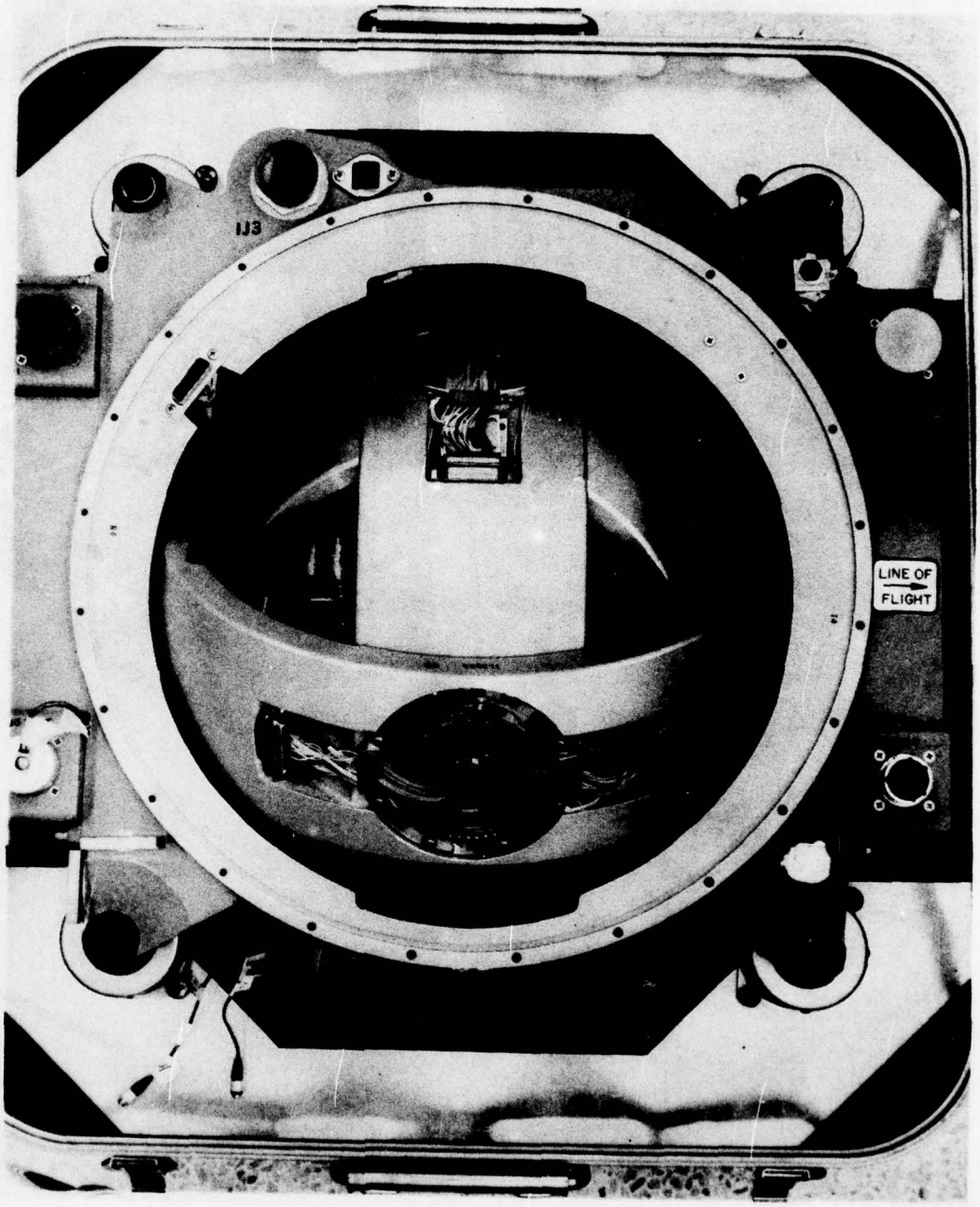


FIGURE 6.1-3. SLEWED GIMBAL POSITION

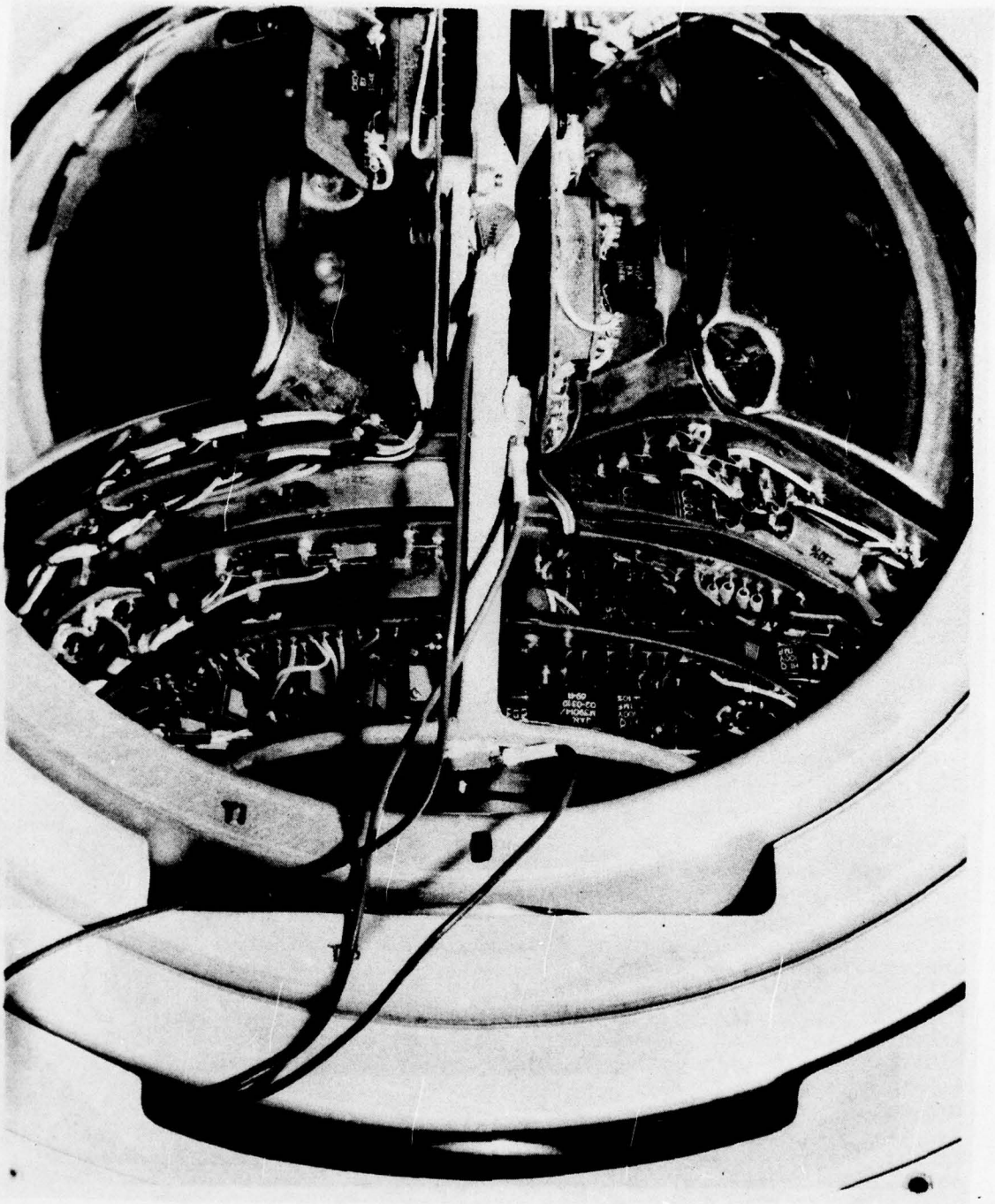


FIGURE 6.1-4. ACCELEROMETER PLACEMENT ON INNER ELEMENT

experienced at the gyros. The nomenclature and accuracy of the accelerometers are given with the rest of the vibration equipment in Paragraph 6.1.1.

The accelerometers attached to the inner element were so oriented that each is sensitive to one axis of vibration. The wires attached to the accelerometers were carefully routed outside the IMU through the pressurization valve hole in the IMU casting. The valve had been removed previously. An inert compound was placed around the wires to ensure that no thermal problems would develop.

Three accelerometers were attached to the IMU mounting fixture, to control input vibration levels, and three were mounted to the IMU. Two more accelerometers were used to check cross-coupling. The final accelerometer was used as a control to shut off the vibration machine if it exceeded a specified limit.

Optical mirrors were attached to the precision surface on the IMU case and on the IMU holding fixture. Two theodolites were set up to measure case rotation during vibration and the repeatability of each isolator by measuring before and after each vibration.

The GEANS IMU LRU Test Program was loaded in the DCU and the "GG" (manual sequencing) mode was selected. Sanborn recorders were set up to monitor critical system parameters such as suspension currents and voltages during the vibration tests.

While BITE bit locations were monitored on the CDU and critical parameters monitored on the Sanborn recorders, the system was manually sequenced through secondary support and normal operating temperature of the IMU was achieved. Thermal stabilization was important to ensure that no damage would occur to the bearings during vibration.

The IMU was mounted on the test fixture initially utilizing the 16 Hz isolators in the vertical axis as shown in Figure 6.1-5. A close-up of the IMU in the vertical position is shown in Figure 6.1-6. This figure also shows the mounting of a set of optical mirrors.

Vibration inputs were first applied sinusoidally, then random in each axis as follows:

1. Sinusoidal

   0.2 inch peak to peak 5 to 7 Hz

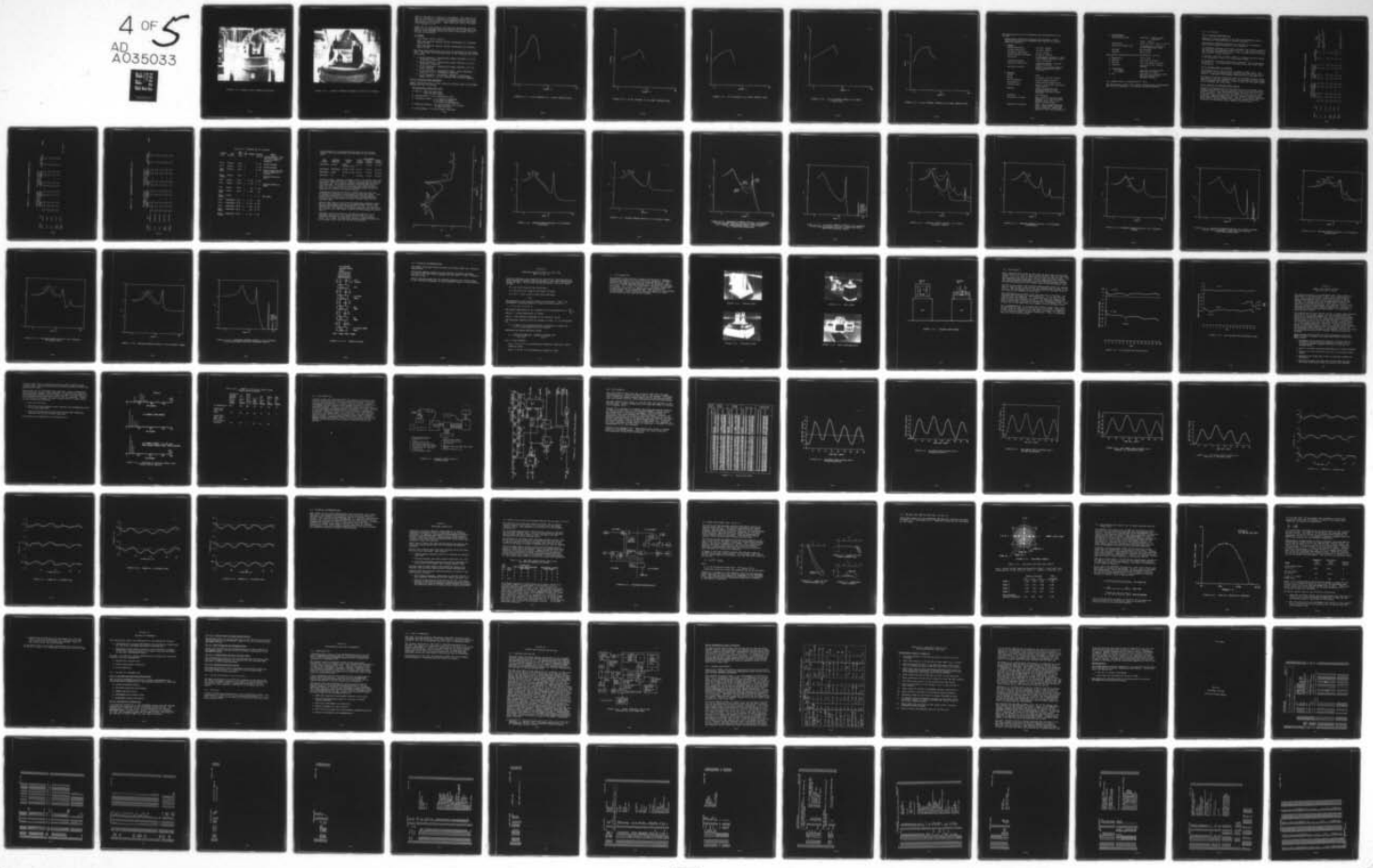
   0.5 g peak 7 to 2000 Hz

   One sweep up and down, one octave per minute.

An additional sweep of 1 g up and down from 10 Hz to 100 Hz was also performed. During these sweeps a determination was made of (a) the frequency of the maximum sway of the IMU, and (b) the

AD-A035 033 HONEYWELL INC ST PETERSBURG FLA AEROSPACE DIV F/G 17/7
STANDARD PRECISION NAVIGATOR/GEANS MODIFICATIONS FOR EAR MOTION--ETC(U)
NOV 76 D GIONET, P E HALL, S SAMSEL F33615-74-C-1068
UNCLASSIFIED 176-13551 AFAL-TR-76-71 NL

4 OF 5
AD A035033



A7409-103

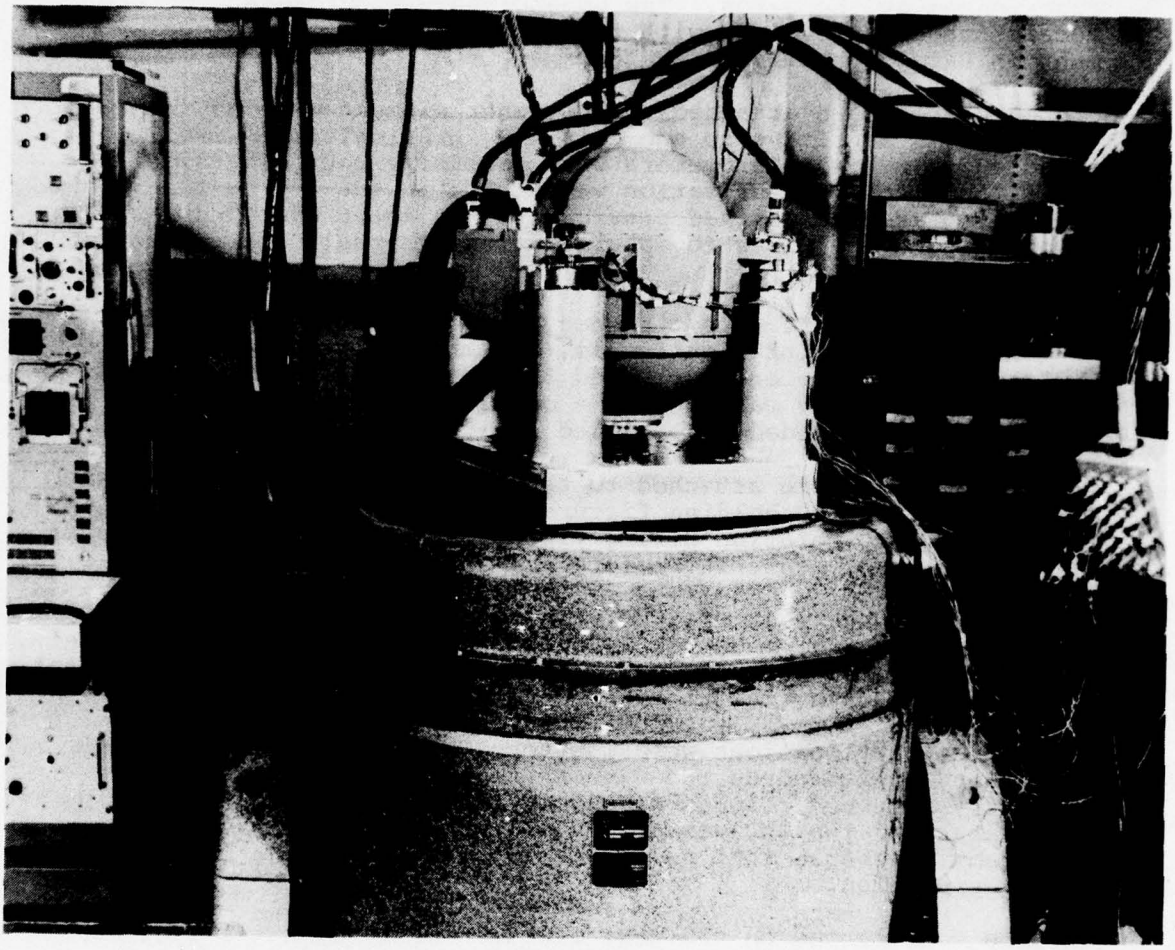


FIGURE 6.1-5. VERTICAL AXIS VIBRATION POSITION

A7409-104

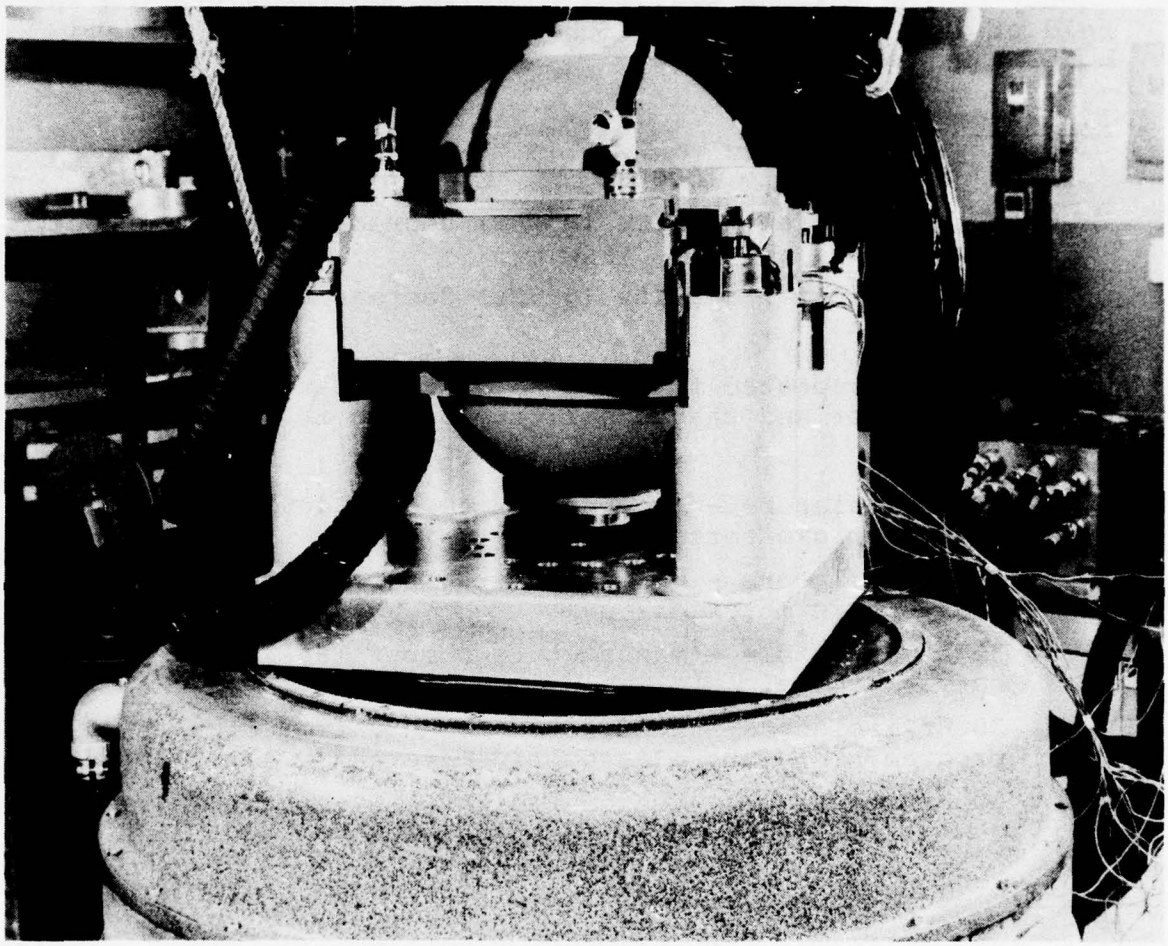


FIGURE 6.1-6. CLOSE-UP SHOWING PLACEMENT OF ONE SET OF MIRRORS

sway of the IMU as a function of frequency. The sway of the IMU as a function of frequency was approximated by the movement of the reticle lines in the theodolite which were later calibrated in arc-seconds. These plots are given in Figures 6.1-7 through 6.1-11.

After the 1 g sine sweep up and down was performed, the frequency of the maximum sway was selected and the vibration was held at that frequency until the blur of the light, top and bottom, was measured.

2. Random

$0.02\ g^2/Hz$ 300 to 1000 Hz

With the spectral density (g^2/Hz) decreasing at 12 db/oct, 300 to 20 Hz

With the spectral density (g^2/Hz) decreasing at 6 db/oct, 300 to 20 Hz.

The above was repeated for five sets of isolators in all three axes. The order and characteristics of the isolators are given as follows:

1. 16 Hz isolators - manufacture number 34009911, $Q \approx 3.5$, elastomeric material
2. 40 Hz isolators - manufacture number T64-X13, $Q \approx 4.0$, elastomeric material
3. 35 Hz isolators - manufacture number T64-X14, $Q \approx 3.0$, butyl material
4. 30 Hz isolators - designated "NOAH", from classified program, $Q \approx 4.0$, elastomeric material
5. 30 Hz isolators - designated "SPRING", manufacture number 22539-1, $Q \approx 1.5$, spring with friction damping.

6.1.1 Vibration Test Equipment

General characteristics of the vibration machine used for the EARS system test are as follows:

MB Electronics Model MB C-126

- Force: 7800 lbs peak Sine
  5500 lbs rms Random
- Acceleration: 60 g's maximum no load
- Frequency Range: 5 to 3000 Hz Sinusoidal
  20 to 2000 Hz Random
  5 to 2000 Hz Superimposed
- Mounting Surface: 16 inch diameter bolt pattern
  17 mounting pads
- Displacement: 0.8 inch double amplitude

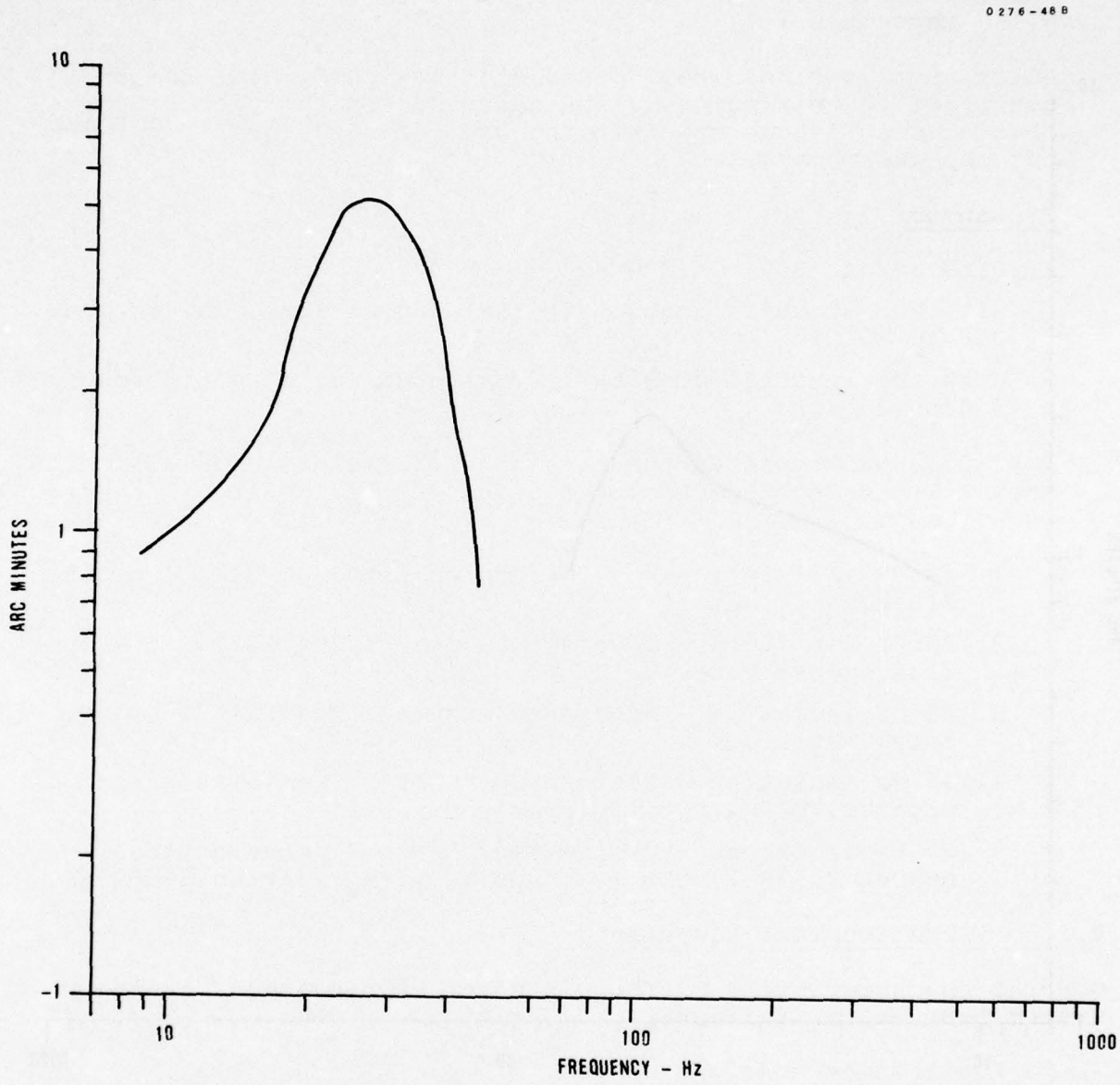


FIGURE 6.1-7. 16 Hz ISOLATOR (1/2 G SINE) VERTICAL AXIS

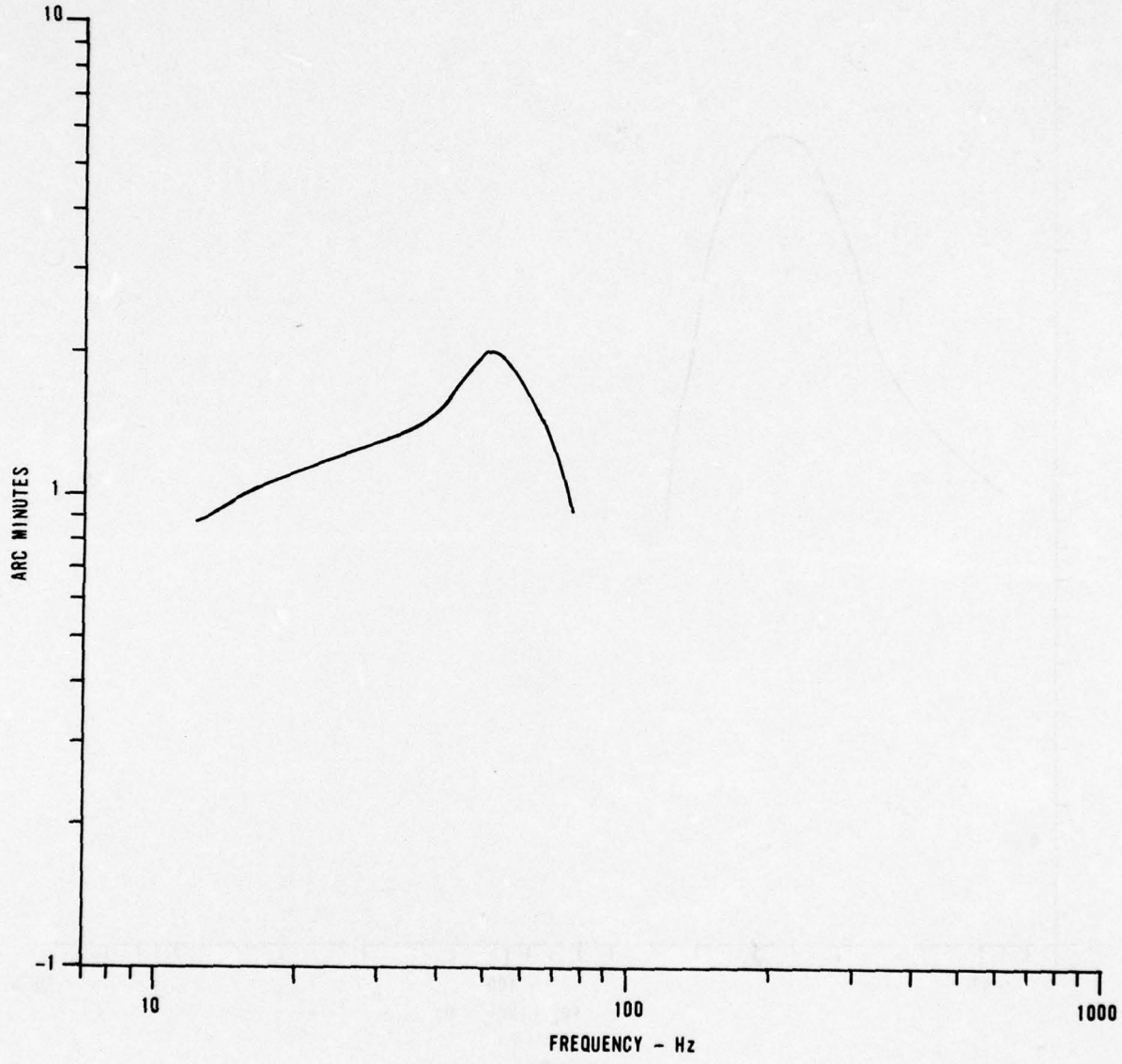


FIGURE 6.1-8. 40 Hz ISOLATOR (1/2 g SINE) VERTICAL AXIS

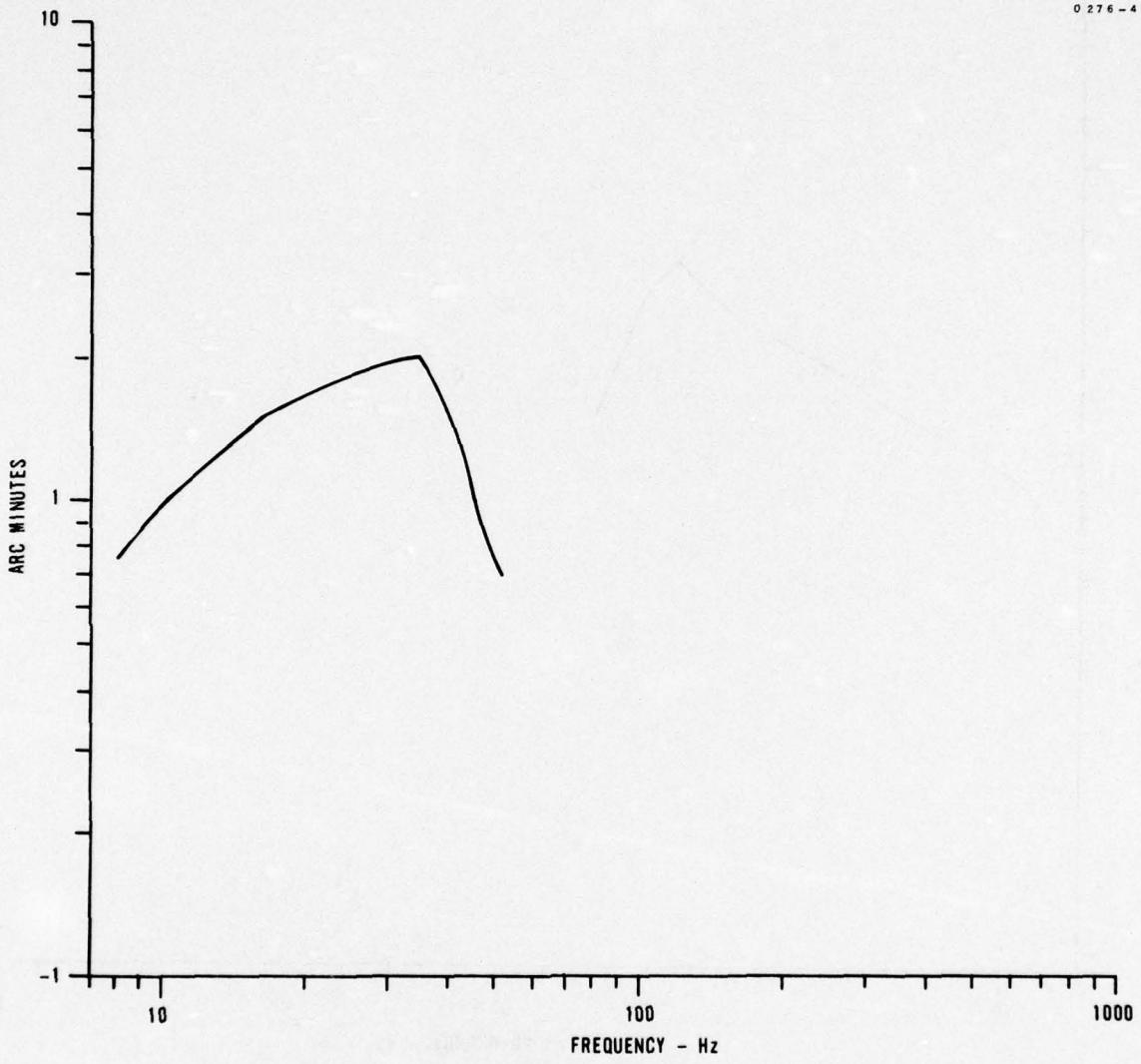


FIGURE 6.1-9. 35 Hz ISOLATOR (1/2 g SINE) VERTICAL AXIS

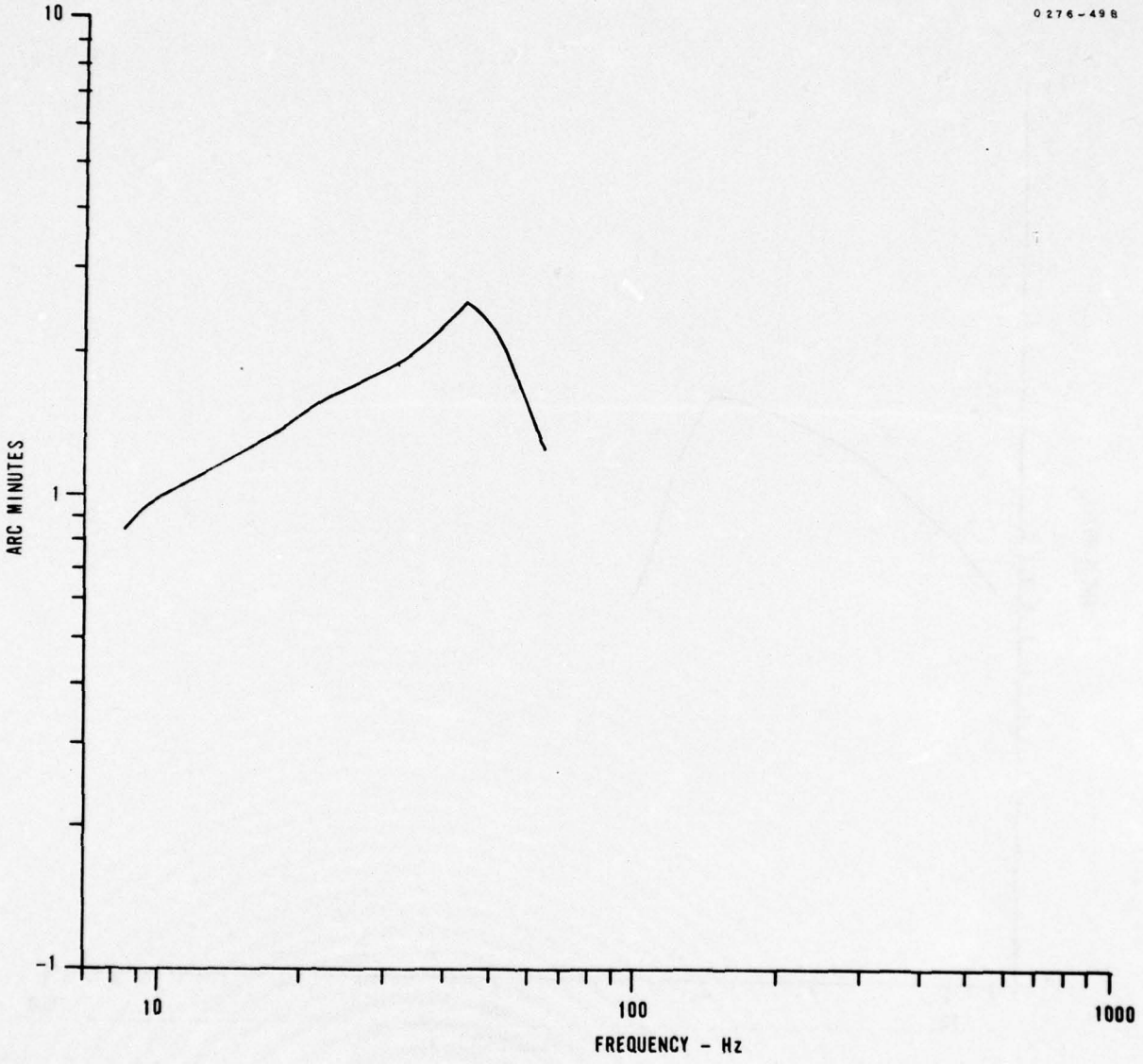


FIGURE 6.1-10. 30 Hz ISOLATOR (NOAH) (1/2 g SINE)
VERTICAL AXIS

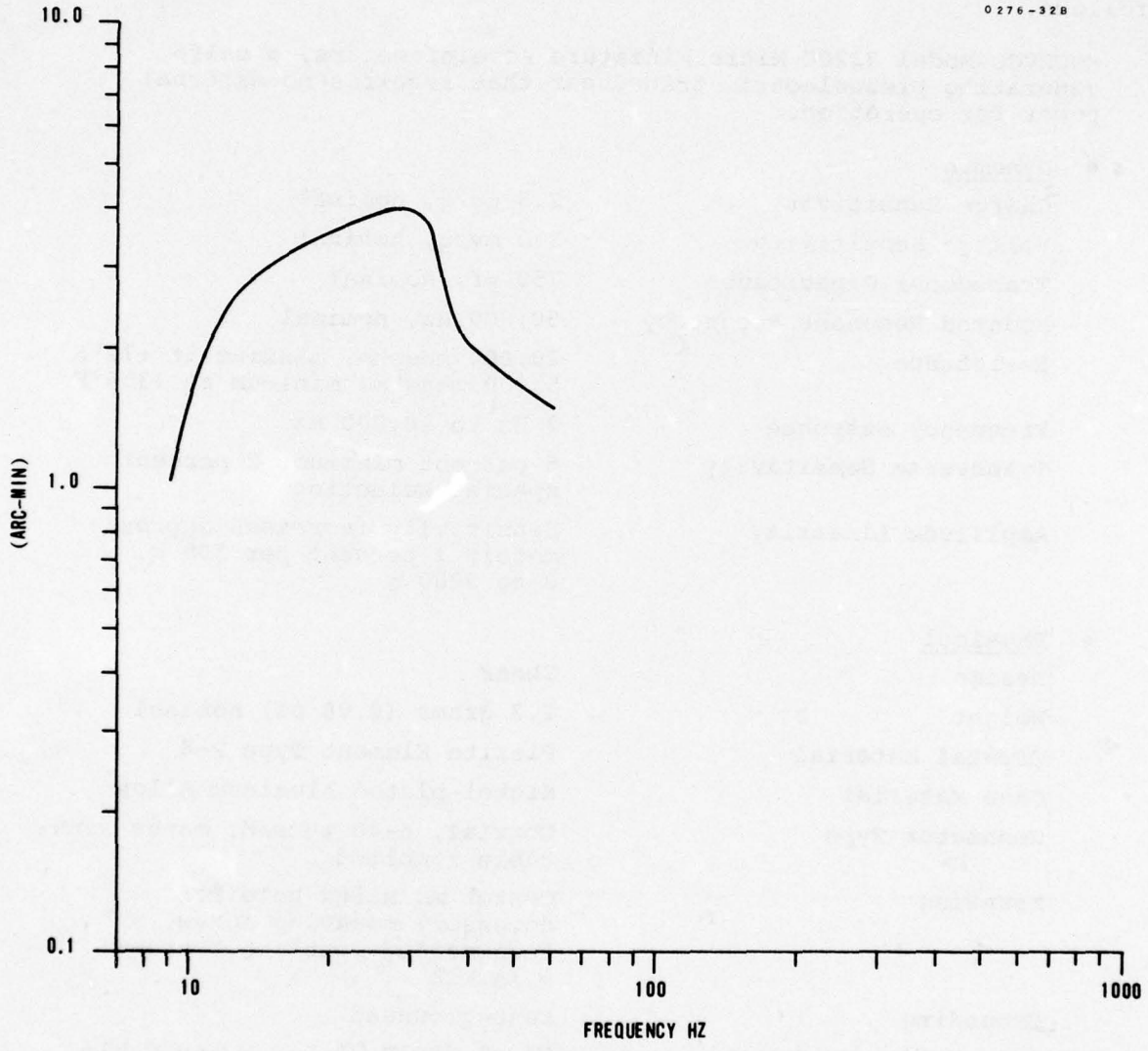


FIGURE 6.1-11. 30 Hz ISOLATOR (SPRING)(1/2 g SINE) VERTICAL AXIS

The characteristics of the instrumentation accelerometers are as follows:

ENDEVCO Model 2220C Micro Miniature Accelerometers, a self-generating piezoelectric transducer that requires no external power for operation.

- Dynamic

Charge Sensitivity	2.8 pc/g, nominal
Voltage Sensitivity	3.0 mv/g, nominal
Transducer Capacitance	750 pf, nominal
Mounted Resonant Frequency	50,000 Hz, nominal
Resistance	20,000 megohm, minimum at +72°F 5,000 megohm, minimum at +350°F
Frequency Response	2 Hz to 10,000 Hz
Transverse Sensitivity	5 percent minimum, 2 percent special selection
Amplitude Linearity	Sensitivity increases approximately 1 percent per 500 g, 0 to 5000 g

- Physical

Design	Shear
Weight	2.3 grams (0.08 oz) nominal
Crystal Material	Piezite Element Type P-8
Case Material	Nickel-plated Aluminum Alloy
Connector Type	Coaxial, 6-40 thread, mates with cable supplied
Mounting	Center mounting hole for accessory mounting screw. Recommended mounting torque: 5 in.-lb
Grounding	Case grounded
Accessories Included	Model 3091B-72 Low Noise Cable Assembly, 6 ft, 200 pf nominal. Mounting screw 2-56 x 3/8, washer, and hex wrench
Accessories Available	Model 12746 Insulated Mounting Screw. Model 3090A Extension Cable Assemblies. Model EJ34 Adapter to join cable assemblies.

- Environmental

Acceleration Limits	Vibration: ±1000 g (peak), sinusoidal
	Shock: ±5000 g
Temperature	-65°F to +350°F (-54°C to +177°C)
Base Strain Sensitivity	13 equivalent g, nominal, at 250 microinch/inch strain
Altitude	Not affected
Humidity	Epoxy sealed

Some general characteristics of the environmental area are:

• Temperature	70°F to 80°F
• Humidity	Less than 60 percent
• Pressure	28 to 32 inches of mercury
• Acoustics	Less than 75 dbA (overall reading)
• Cleanliness	
0.5 micron	Less than 2 million counts
5.0 micron	Less than 500 counts
• RFI	Equivalent to lightning strike one mile distant from Honeywell complex

6.2 CURRENT STATUS OF TRANSMISSIBILITY TESTS

The detail plots of each of the twelve instrumentation accelerometers are on file at Honeywell. All analysis has been completed.

6.3 TEST RESULTS

6.3.1 Isolator Repeatability

Table 6.3-1 gives a summary of the optical measurements made to determine the repeatability of various isolators.

The Honeywell physical standards lab provided the theodolites which are certified accurate to ±5 arc-seconds.

A preliminary analysis of the data indicates that stiffer isolators are slightly more repeatable than the 16 Hz. The spring isolator has the worst repeatability since it has a tendency to stay at the last position of the vibration.

In general, isolators of butyl rubber or elastomer material appear to be repeatable in the 15 to 20 arc-second range.

The phenomena of isolator settling was observed, and is discussed in TCL No. 5. All measurements were made where this effect would be minimized.

6.3.2 Maximum Sway of Isolators

The maximum sway of each isolator is given in Table 6.3-2. The large angle in the vertical axis indicated that the IMU was out of balance. Subsequent measurements described below confirmed this.

The center of gravity of the IMU used for the EARS vibration transmissibility tests was measured using a beam balance and knife edges. Each measurement was repeated at least 8 times and the total spread of the readings was ±0.07 inch.

6.3.3 Analysis of Vibration Test Results

Vibration transmissibilities from vehicle input to platform stable element were plotted from the vibration test results and from calculations using a five Spring-Mass-Damper Model for the 16, 35 and 40 Hz isolators. The 16 and 40 Hz isolators, made from silicone elastomer, displayed amplitude sensitive resonant frequencies and structural damping characteristics. The 35 Hz isolators, made with butyl rubber, did not exhibit the amplitude sensitive resonant frequency and displayed viscous damping characteristics.

TABLE 6.3-1. REPEATABILITY OF ISOLATORS

Isolator	Axis		Measurement of Difference of IMU and Fixture Prior to 1/2 g Vibration		Measurement of Difference of IMU and Fixture After 1/2 g Vibration		Difference		Comment
			Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation	
16 Hz	Vertical	TH1	01' 51"	12' 31"	01' 59"	12' 18"	09"	13"	Measurement taken after vibration of 1 g and random.
		TH2	-(00' 04")	36' 17"	+(00' 02")	36' 16"	06"	01"	
40 Hz	Vertical	TH1	-(00' 01")	09' 10"	-(00' 07")	09' 37"	06"	27"	Large reading in elevation may have been caused by loose mirror.
		TH2	-- --	-(45' 40")	-- --	-(43' 24")	--	01' 16"	
35 Hz	Vertical	TH1	-(05' 13")	-(01' 27")	-(05' 13")	-(01' 24")	00"	03"	
		TH2	02' 20"	02' 14"	02' 26"	02' 06"	06"	20"	
30 Hz (NOAH)	Vertical	TH1	04' 13"	02' 35"	04' 10"	02' 40"	03"	05"	
		TH2	05' 22"	01' 21"	05' 34"	01' 27"	12"	06"	
30 Hz Spring	Vertical	TH1	01' 35"	06' 44"	01' 07"	04' 36"	28"	03' 29"	
		TH2	06' 08" 01°	02' 38"	06' 39" 01°	00' 42"	31"	02' 04"	
16 Hz (Special)	Vertical	TH1	04' 00"	10' 49"	03' 53"	11' 08"	07"	19"	Special run of 16 Hz isolators with gimbals slewed.
		TH2	00' 31"	59' 10"	00' 38"	59' 30"	07"	20"	

TABLE 6.3-1. REPEATABILITY OF ISOLATORS (Cont)

Isolator	Axis		Measurement of Difference of IMU and Fixture Prior to 1/2 g Vibration		Measurement of Difference of IMU and Fixture After 1/2 g Vibration		Difference		Comment
			Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation	
16 Hz	Lateral	TH1	03' 08"	09' 21"	03' 17"	09' 01"	09"	20"	
		TH2	00' 18"	59' 50"	00' 14"	59' 53"	04"	03"	
40 Hz	Lateral	TH1	06' 16"	06' 39"	06' 24"	06' 46"	08"	07"	
		TH2	00' 41"	58' 23"	00' 40"	58' 29"	01"	06"	
35 Hz	Lateral	TH1	06' 57"	07' 55"	06' 40"	07' 51"	17"	04"	
		TH2	00' 34" 1°	02' 14"	00' 28" 1°	02' 20"	06"	06"	
30 Hz (NOAH)	Lateral	TH1	05' 11"	07' 20"	05' 22"	07' 20"	11"	00"	
		TH2	01' 09" 1°	00' 30"	01' 25" 1°	00' 35"	16"	05"	
30 Hz (Spring)	Lateral								(Not performed.)

TABLE 6.3-1. REPEATABILITY OF ISOLATORS (Cont)

Isolator	Axis		Measurement of Difference of IMU and Fixture Prior to 1/2 g Vibration		Measurement of Difference of IMU and Fixture After to 1/2 g Vibration		Difference		Comment
			Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation	
16 Hz	Longitudinal	TH1	02' 45"	12' 08"	03' 00"	12' 15"	15"	07"	
		TH2	-(00' 41")	59' 55"	-(00' 27") 1°	00' 08"	14"	13"	
40 Hz	Longitudinal	TH1	07' 18"	08' 31"	07' 05"	08' 32"	13"	01"	
		TH2	01' 36"	59' 25"	01' 30"	59' 29"	06"	04"	
35 Hz	Longitudinal	TH1	07' 27"	08' 28"	07' 21"	08' 23"	06"	05"	
		TH2	01' 21" 1°	01' 53"	01' 14" 1°	01' 50"	07"	03"	
30 Hz (NOAH)	Longitudinal	TH1	05' 32"	07' 24"	05' 38"	07' 40"	06"	16"	
		TH2	01' 18" 1°	00' 49"	01' 13" 1°	01' 02"	05"	13"	
30 Hz (Spring)	Longitudinal	TH1	16' 10"	05' 10"	17' 00"	05' 53"	50"	43"	
		TH2	10' 26" 1°	02' 24"	11' 09" 1°	02' 07"	43"	14"	

TABLE 6.3-2. MAXIMUM SWAY OF ISOLATORS

Isolator	Axis	Dwell Freq.	g Level	Azimuth	Elevation	Comment
16 Hz	Vertical	16 Hz	1		over 10'	Azimuth unchanged - large excursion (in excess of 10') out of range of theodolite
40 Hz	Vertical	43 Hz	1		5' 05"	Azimuth unchanged
35 Hz	Vertical	35 Hz	1		1' 20"	Azimuth unchanged
30 Hz (NOAH)	Vertical	30 Hz	1		8' 23"	Azimuth reading not taken - small in comparison to elevation
30 Hz (SPRING)	Vertical	15 Hz	1		4'	Estimated from reticle lines
16 Hz	Lateral	20 Hz	1	3' 25"	1' 40"	
40 Hz	Lateral	30 Hz	1	1' 01"	-- ---	(Elevation reading not taken)
35 Hz	Lateral	35 Hz	1	45"	1' 50"	
30 Hz (NOAH)	Lateral	30 Hz	1	1' 06"	42"	
30 Hz (SPRING)	Lateral	--	1	-- ---	-- ---	(Not taken)
16 Hz	Longitudinal	16 Hz	1	1' 11"	39"	
40 Hz	Longitudinal	35 Hz	1	1' 28"	3' 25"	
35 Hz	Longitudinal	32 Hz	1	1' 44"	6' 40"	
30 Hz (NOAH)	Longitudinal	24 Hz	1	39"	1' 11"	
30 Hz (SPRING)	Longitudinal	20 Hz	1	3' 25"	1' 40"	

Figure numbers of the transmissibility plots for the various isolators and test conditions are identified in the following table.

Type of Data	Vibration Input Axis	Vibration Input	Figure Numbers 16 Hz Isolators	35 Hz Isolators	40 Hz Isolators
Experimental	Vertical	Random, 1/2 and 1 g SIN	6.3.3-1	6.3.3-6	6.3.3-10
Experimental	Longitudinal	1/2 and 1 g SIN	6.3.3-2	6.3.3-7	6.3.3-11
Experimental	Lateral	1/2 and 1 g SIN	6.3.3-3	6.3.3-8	6.3.3-12
Theoretical	All	All	6.3.3-4,5	6.3.3-9	6.3.3-13

Isolator resonant frequency increases of 20 to 30 percent occur when the g level input goes from 1 g down to 1/2 g with the 16 and 40 Hz isolators. The 35 Hz isolator resonant frequency does not change with amplitude. No provision was made in the isolator model, Figure 6.3.3-14, to account for this amplitude sensitive spring rate, but the isolator spring rates and damping were adjusted to match the 1/2 g curve at isolator resonance.

Transmissibilities derived from the random vibration tests had significantly different characteristics from the sine inputs. This is probably attributable to instrumentation characteristics--readout and vibration control circuits must use wider bandwidth filtering than is desirable and circuit response times are too slow even then.

Ambient noise levels in the vibration measurement equipment masked the true IMU transfer function at frequencies above 200 Hz. The apparent transmissibilities "bottomed out" at 0.06 to 0.2 Hz due to the noise. By changing the recording equipment, full scale range from 100 to 10 g's, the signal to noise could be improved by nearly 10 to 1.

Subsequent testing performed on the GEANS SPN IMU using 16 Hz isolators, were run at 5 g's between 200 and 2000 Hz. This increased the signal to noise level by 10:1 in this frequency range. As a result, the additional resonant frequencies predicted by the model at 600, 800, and 1240 Hz were observed

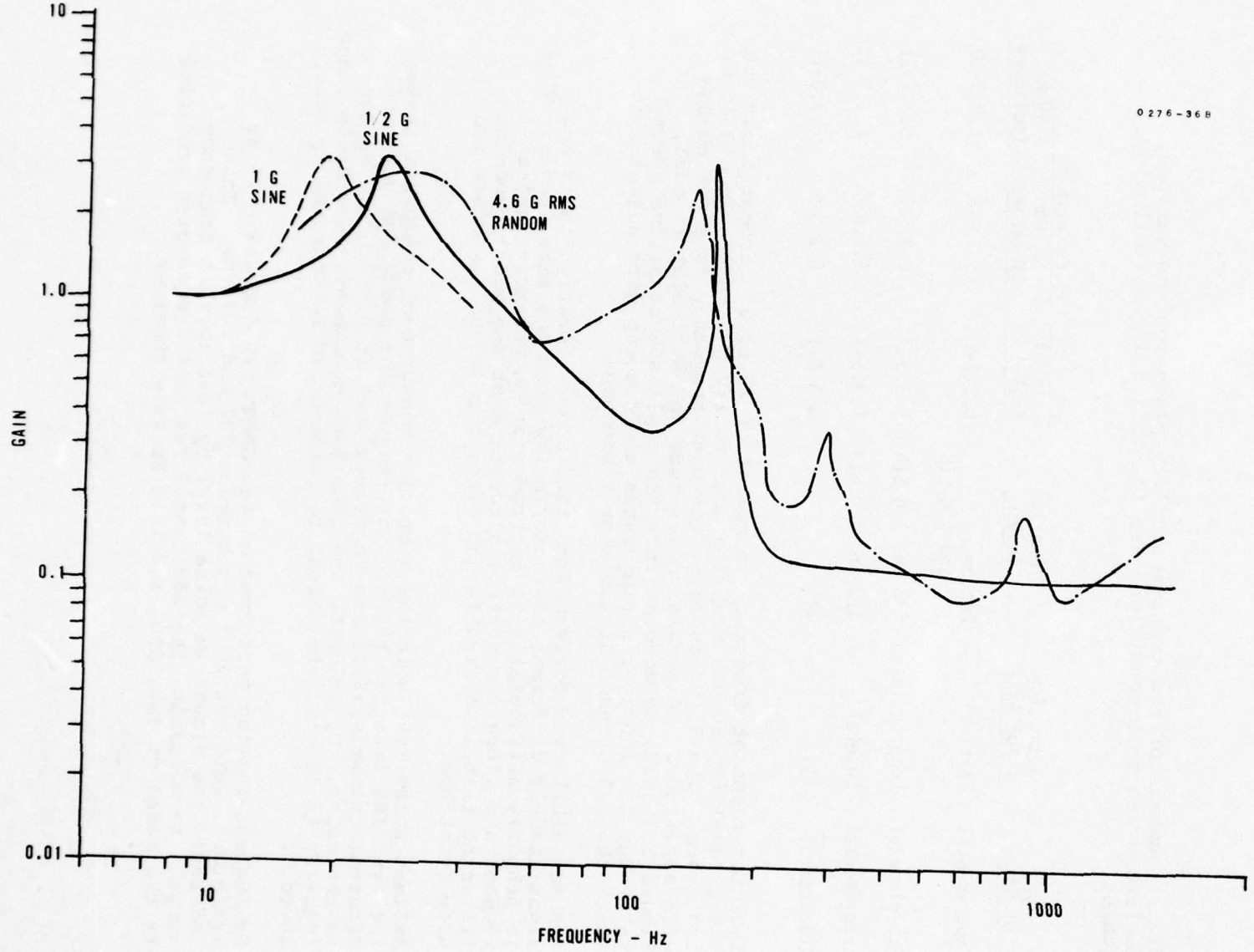


FIGURE 6.3.3-1. MEASURED TRANSFER FUNCTION, 16 Hz ISOLATORS, VERTICAL

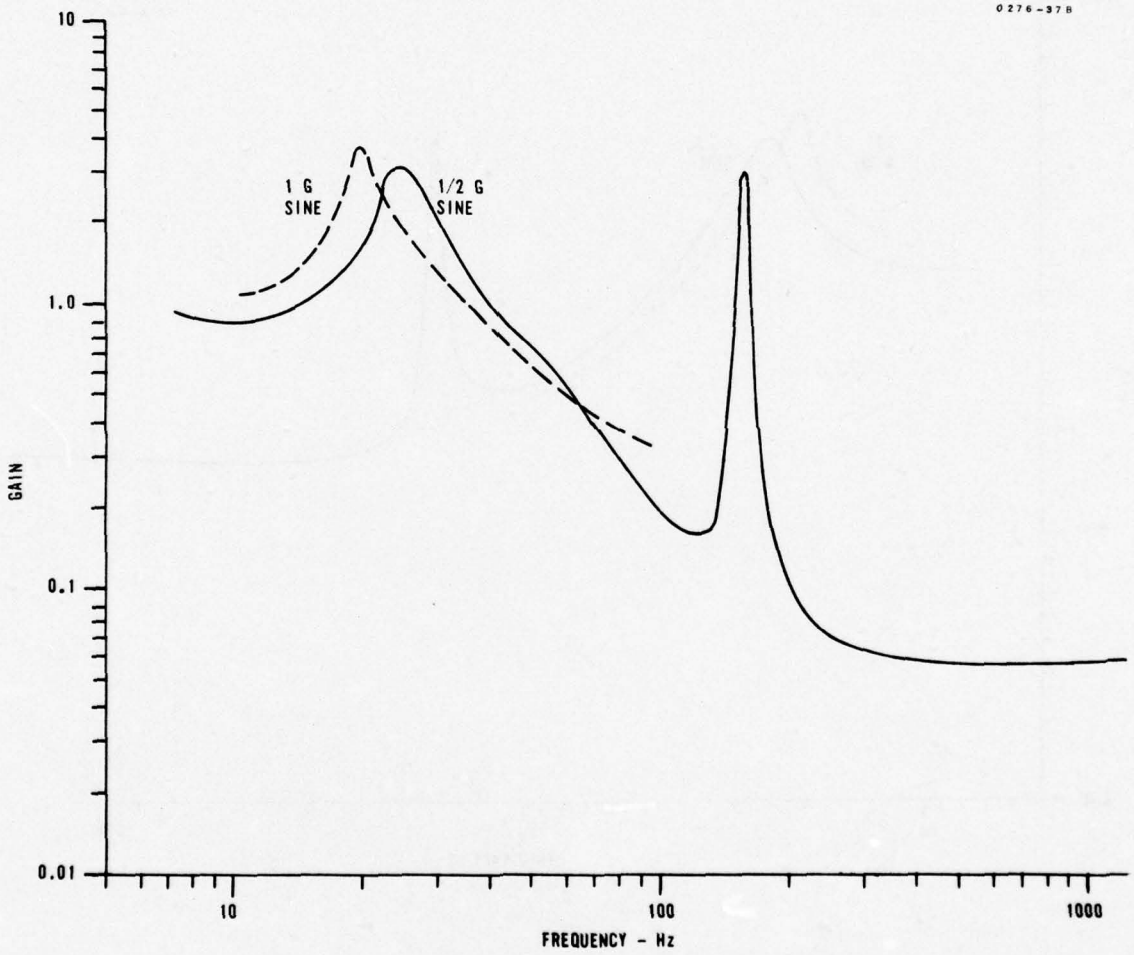


FIGURE 6.3.3-2. MEASURED TRANSFER FUNCTION, 16 Hz ISOLATORS, LONGITUDINAL

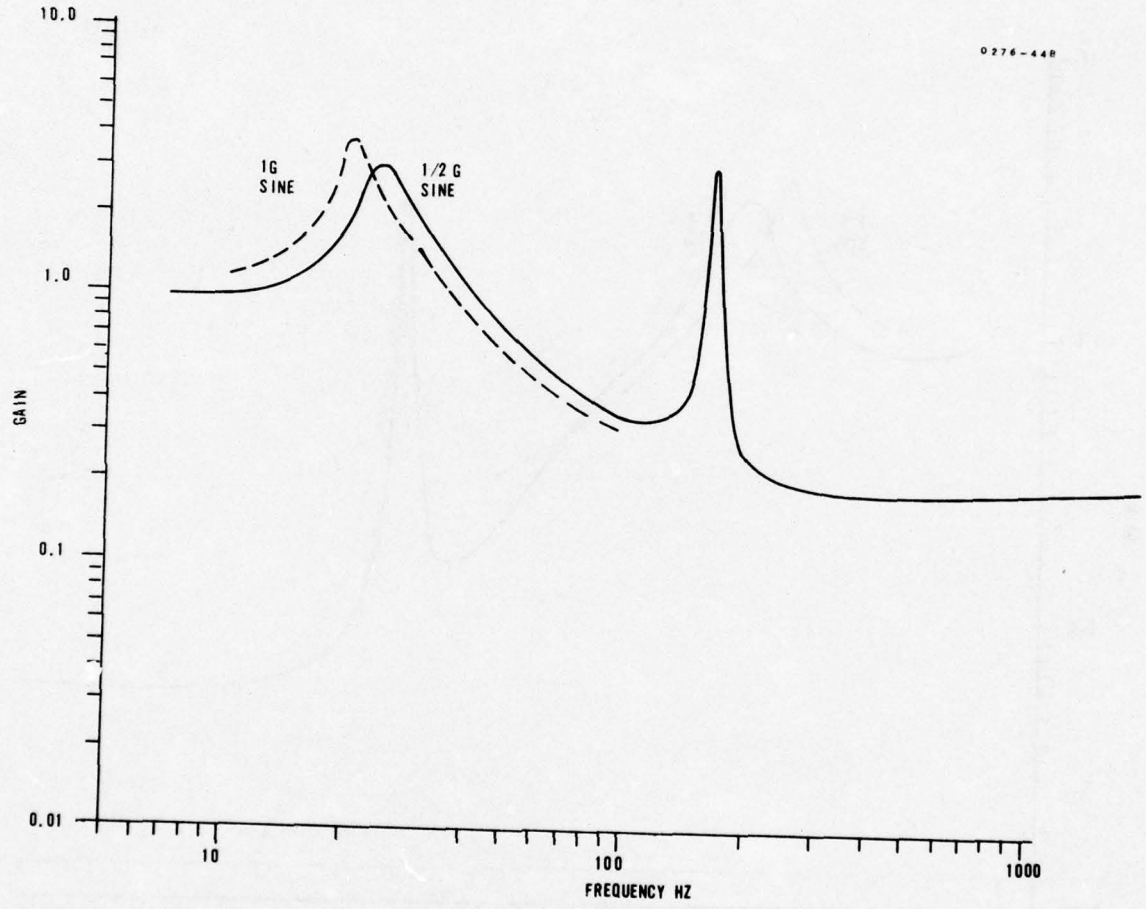


FIGURE 6.3.3-3. MEASURED TRANSFER FUNCTION, 16 Hz ISOLATORS, LATERAL

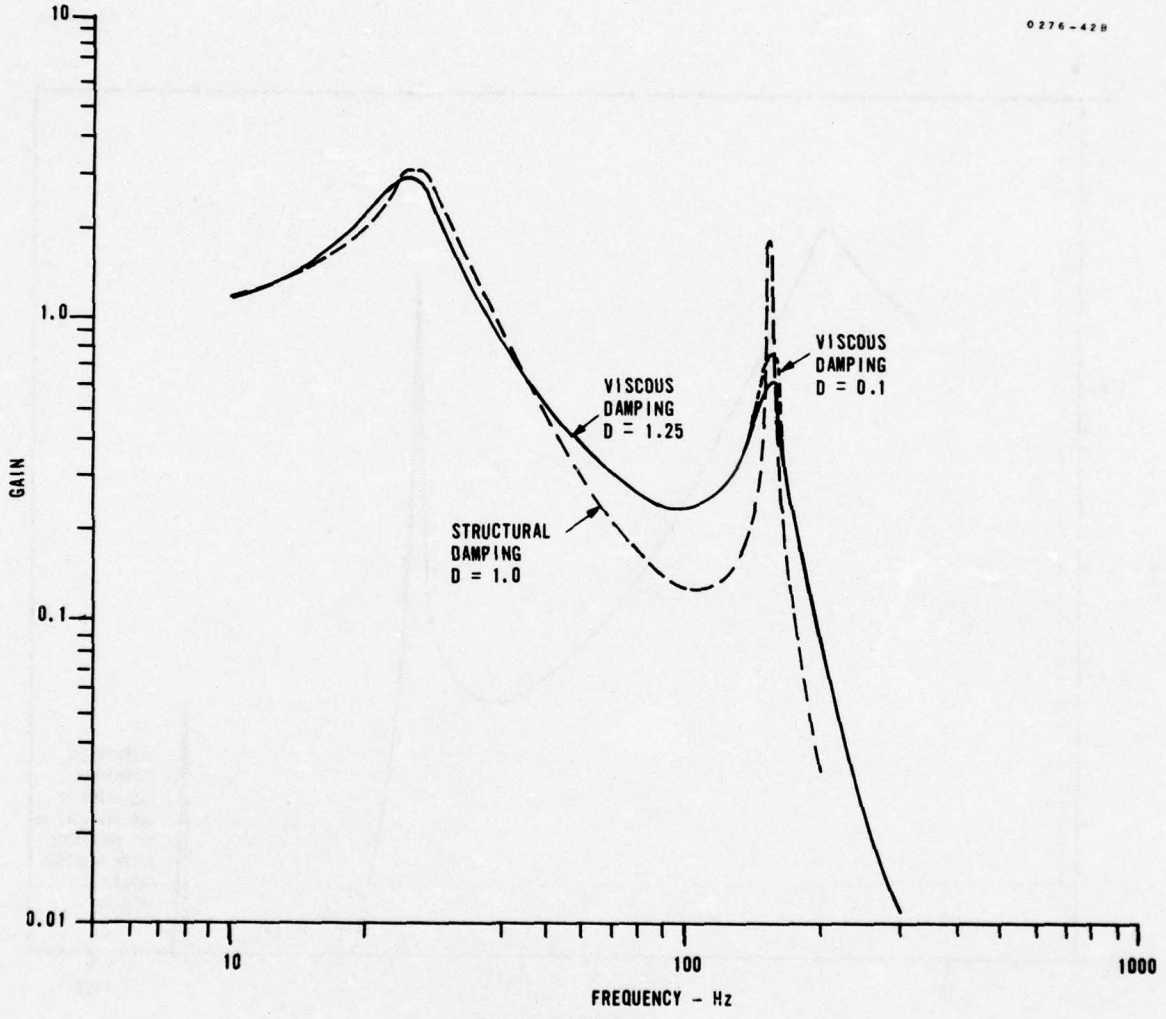


FIGURE 6.3.3-4. THEORETICAL TRANSFER FUNCTION, 16 Hz ISOLATORS, ISOLATOR RESONANT FREQUENCY ADJUSTED TO MATCH EXPERIMENTAL 1/2 g RESULT, GIMBAL DAMPING VARIED TO TRY TO MATCH Q's, 2 SPRING-MASS-DAMPER MODEL

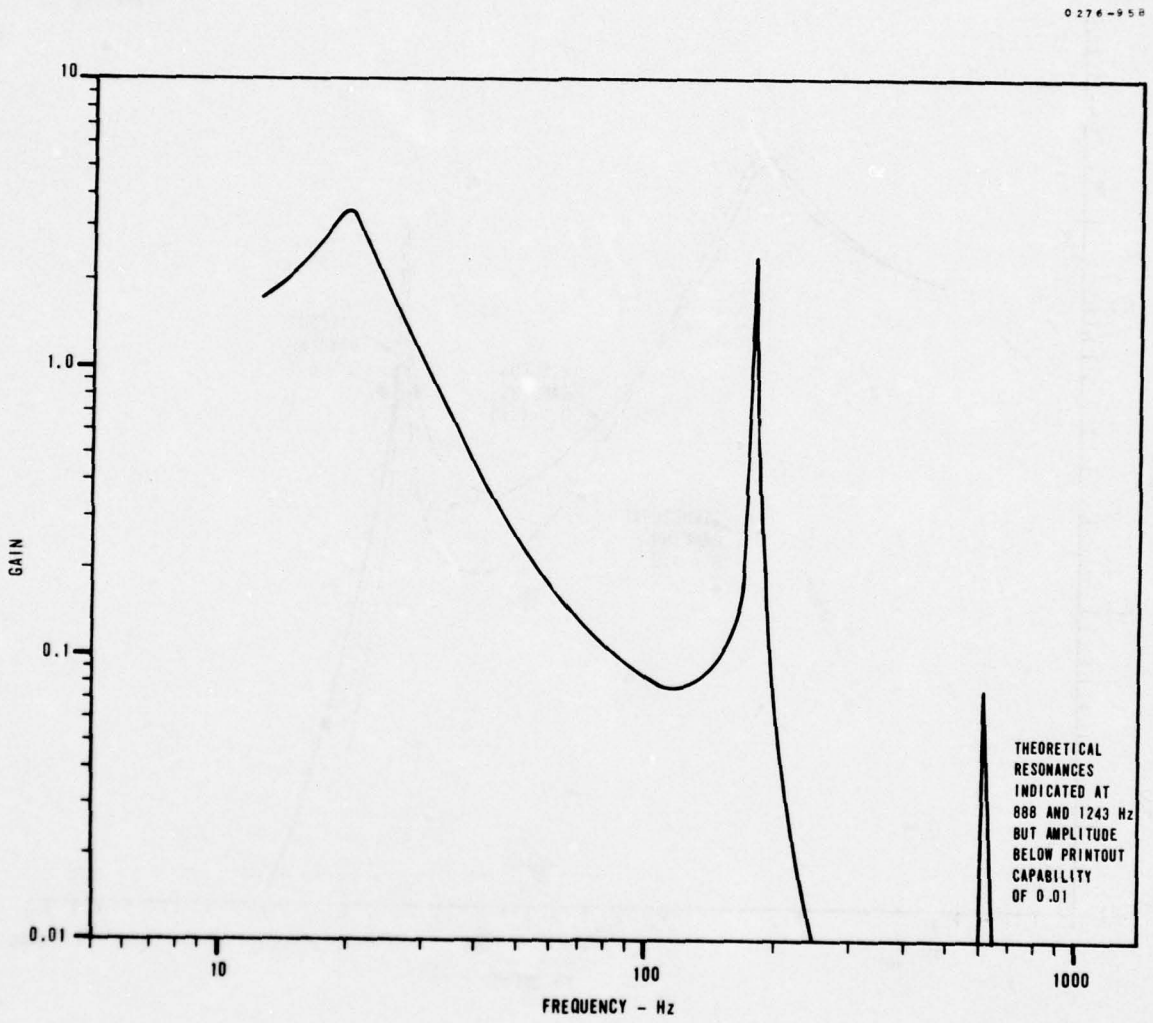


FIGURE 6.3.3-5. THEORETICAL TRANSFER FUNCTION, 16 Hz ISOLATORS, ISOLATOR RESONANCE MODELED AT 20 Hz, 5 SPRING-MASS-DAMPER MODEL WITH STRUCTURAL DAMPING

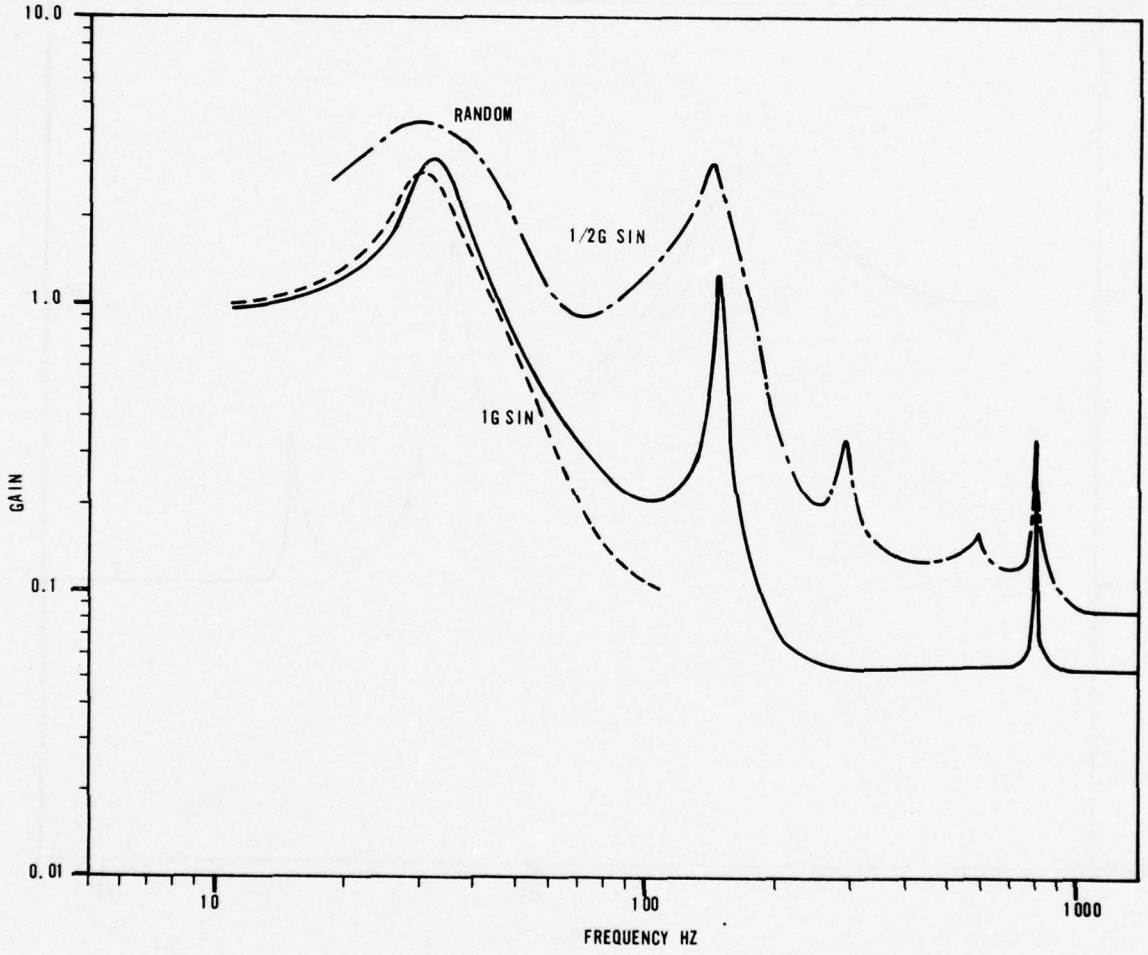


FIGURE 6.3.3-6. MEASURED TRANSFER FUNCTION, 35 Hz (BUTYL) ISOLATORS, VERTICAL

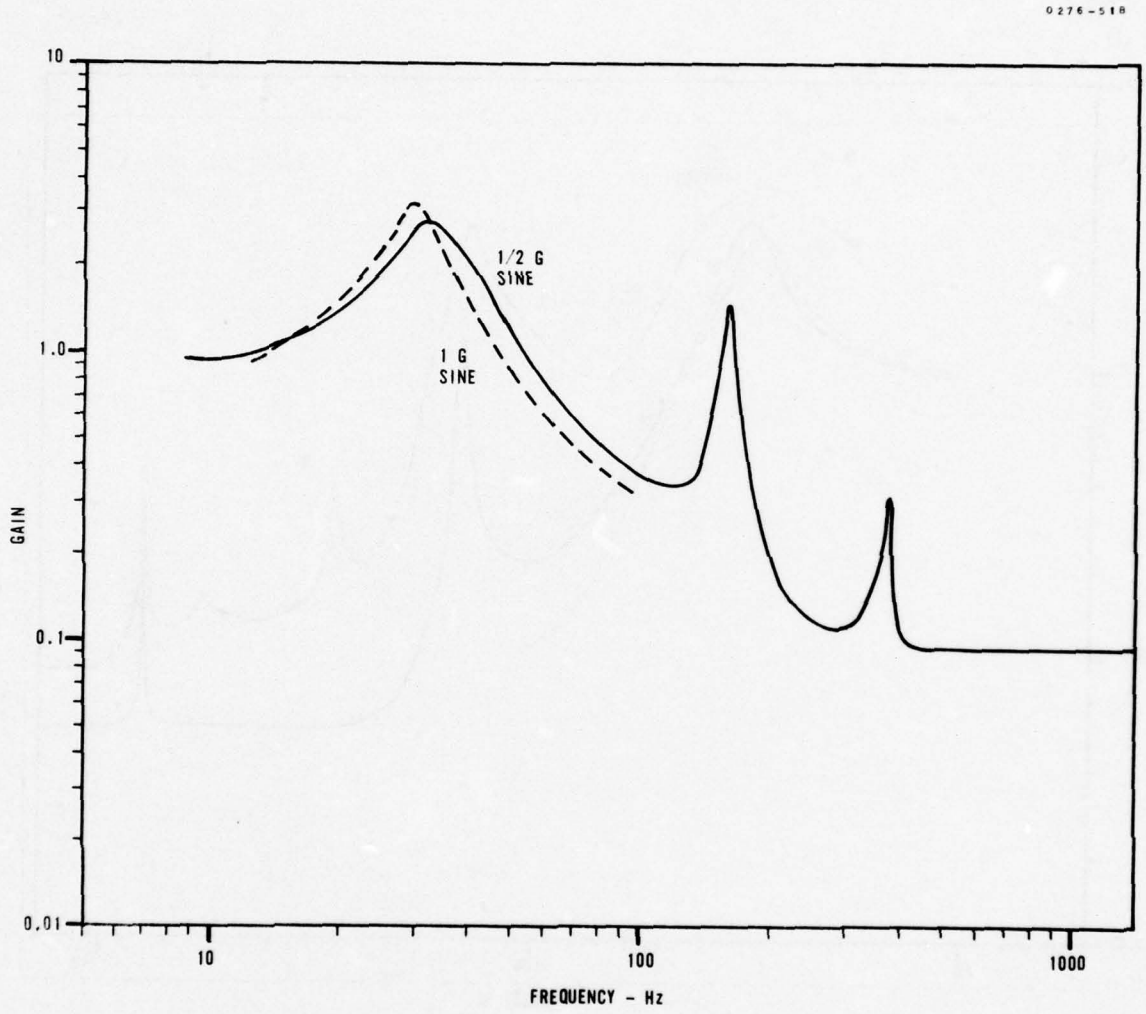


FIGURE 6.3.3-7. MEASURED TRANSFER FUNCTION, 35 Hz ISOLATORS, LONGITUDINAL

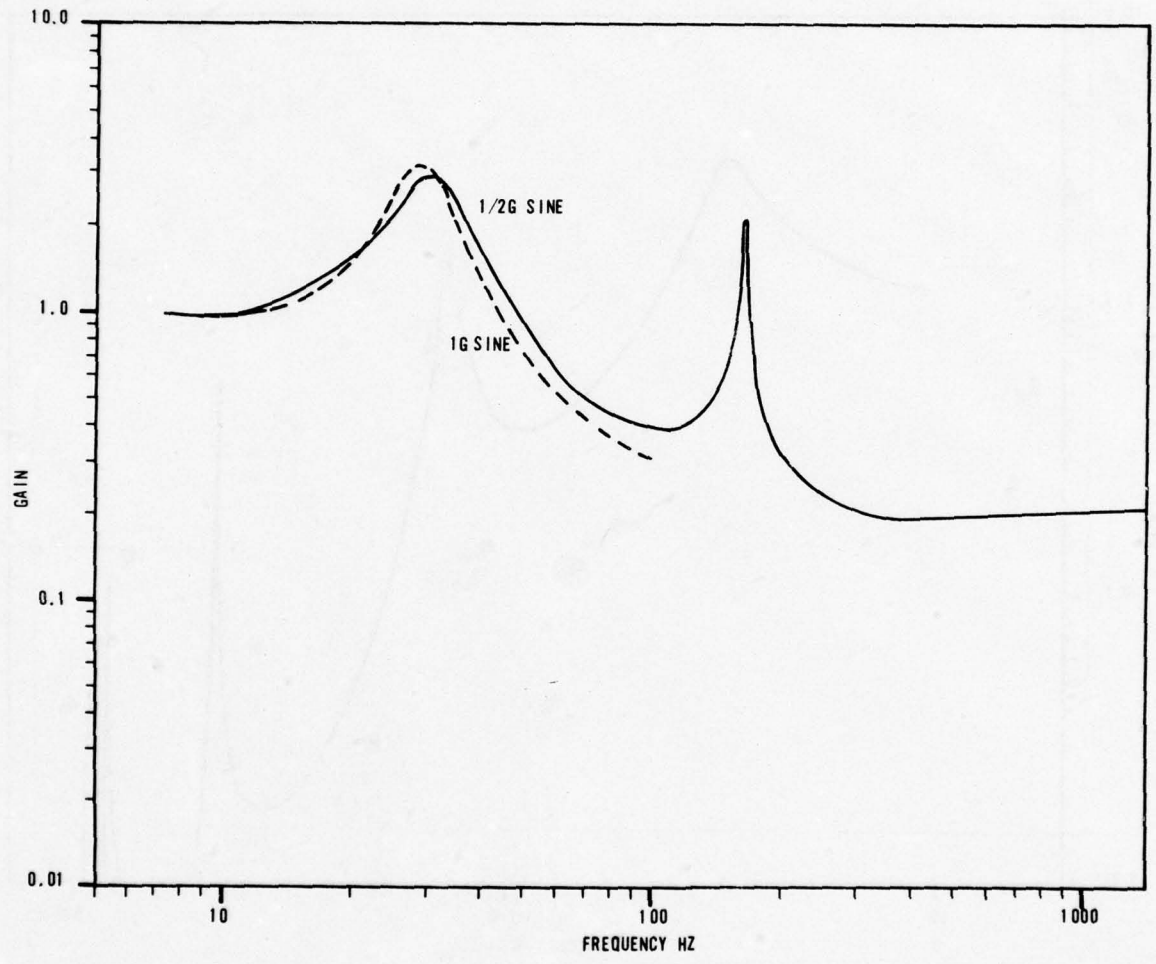


FIGURE 6.3.3-8. MEASURED TRANSFER FUNCTION, 35 Hz ISOLATORS, LATERAL

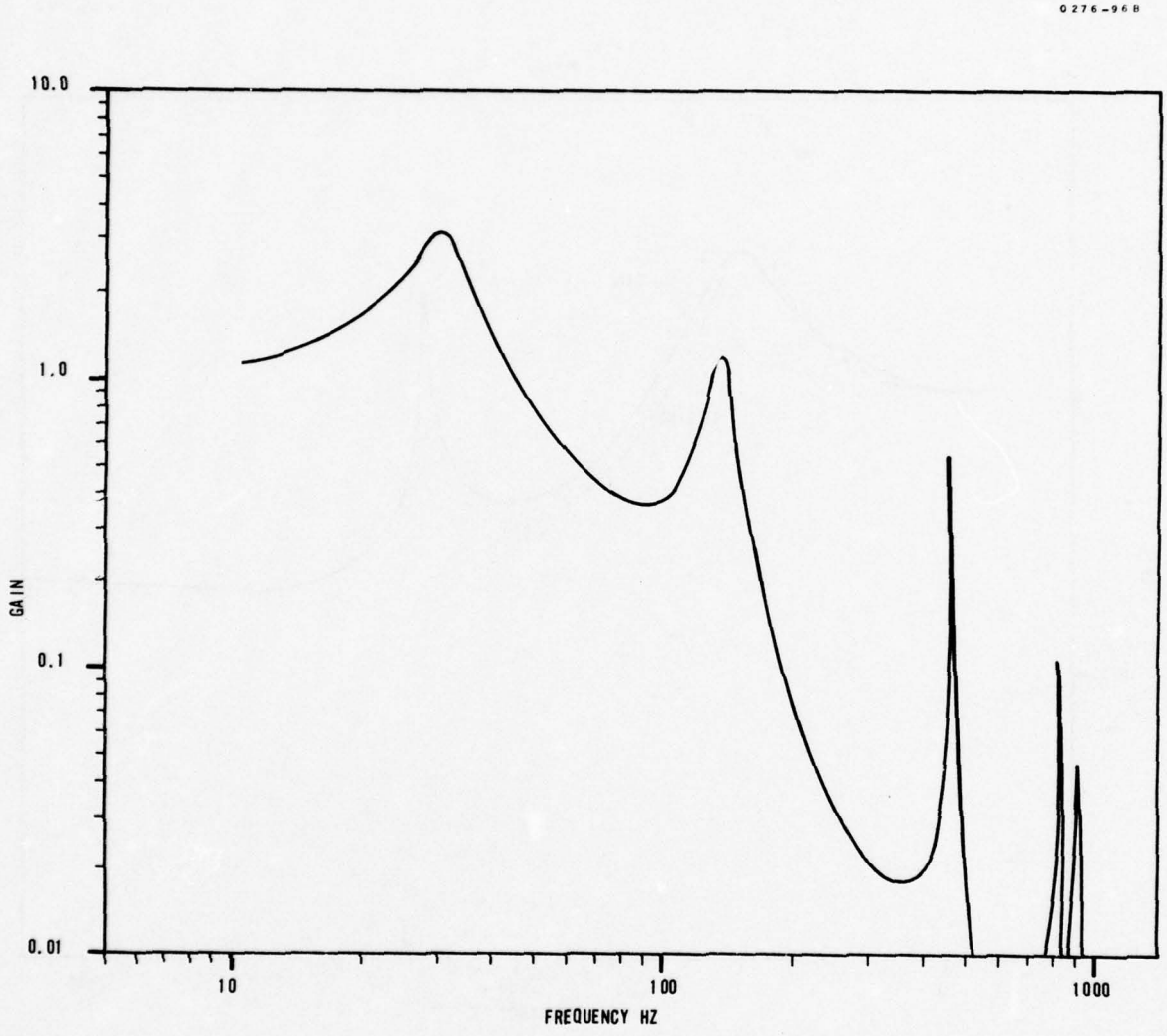


FIGURE 6.3.3-9. THEORETICAL TRANSFER FUNCTION, 35 Hz BUTYL ISOLATORS, FREQUENCY AND Q ADJUSTMENT TO MATCH MEASURED RESPONSE, 5 SPRING-MASS-DAMPER MODEL

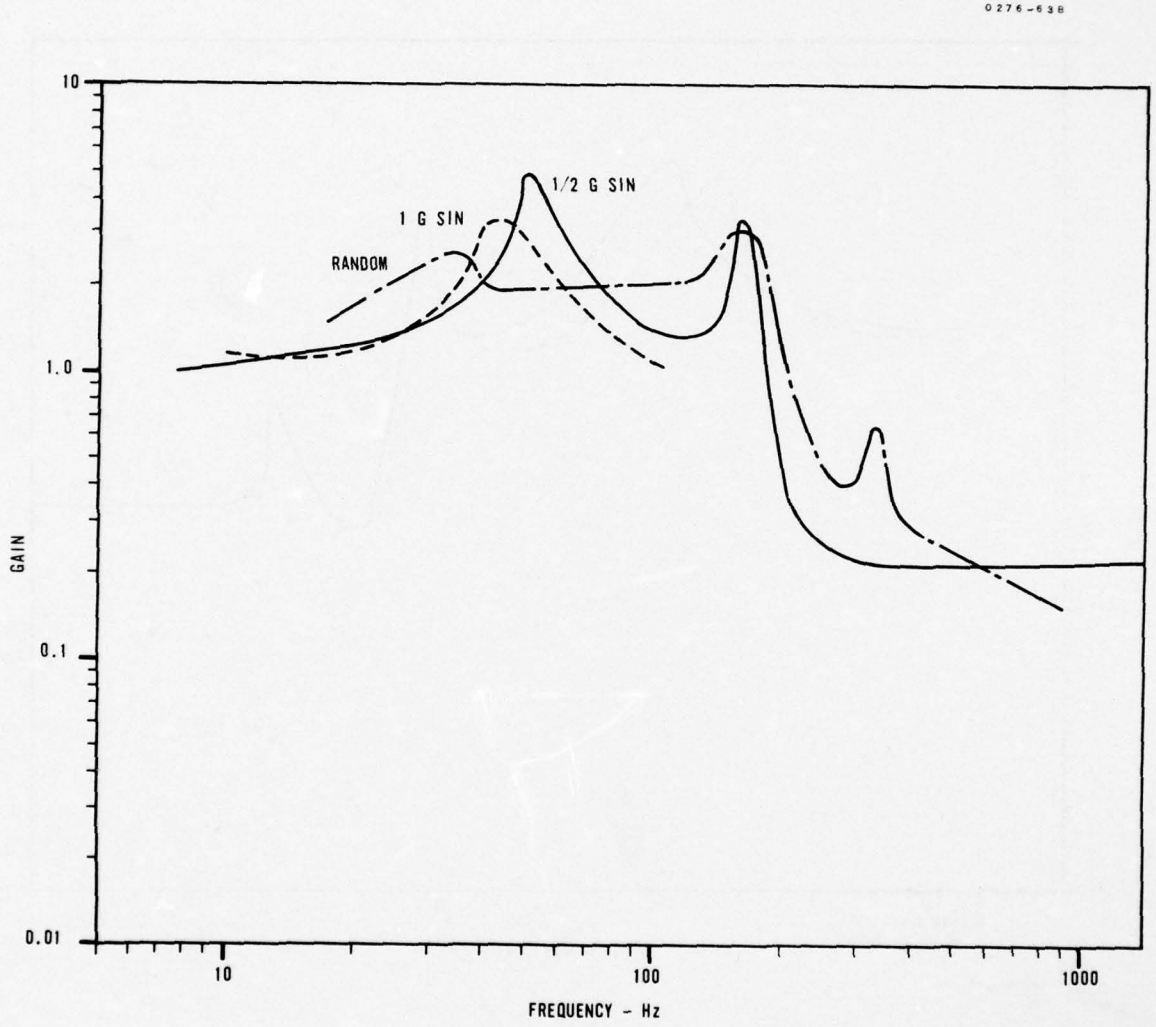


FIGURE 6.3.3-10. MEASURED TRANSFER FUNCTION, 40 HZ ISOLATORS, VERTICAL AXIS

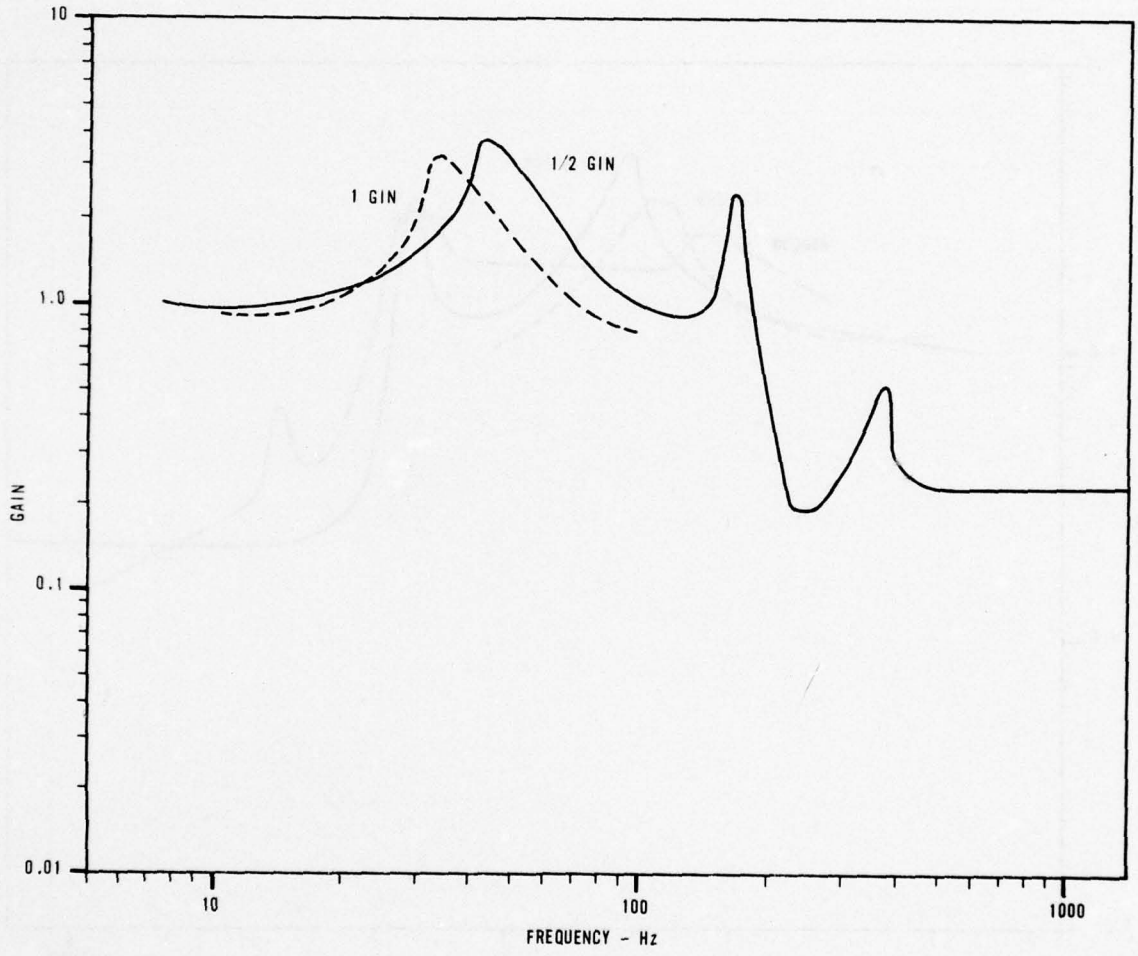


FIGURE 6.3.3-11. MEASURED TRANSFER FUNCTION, 40 Hz ISOLATORS, LONGITUDINAL AXIS

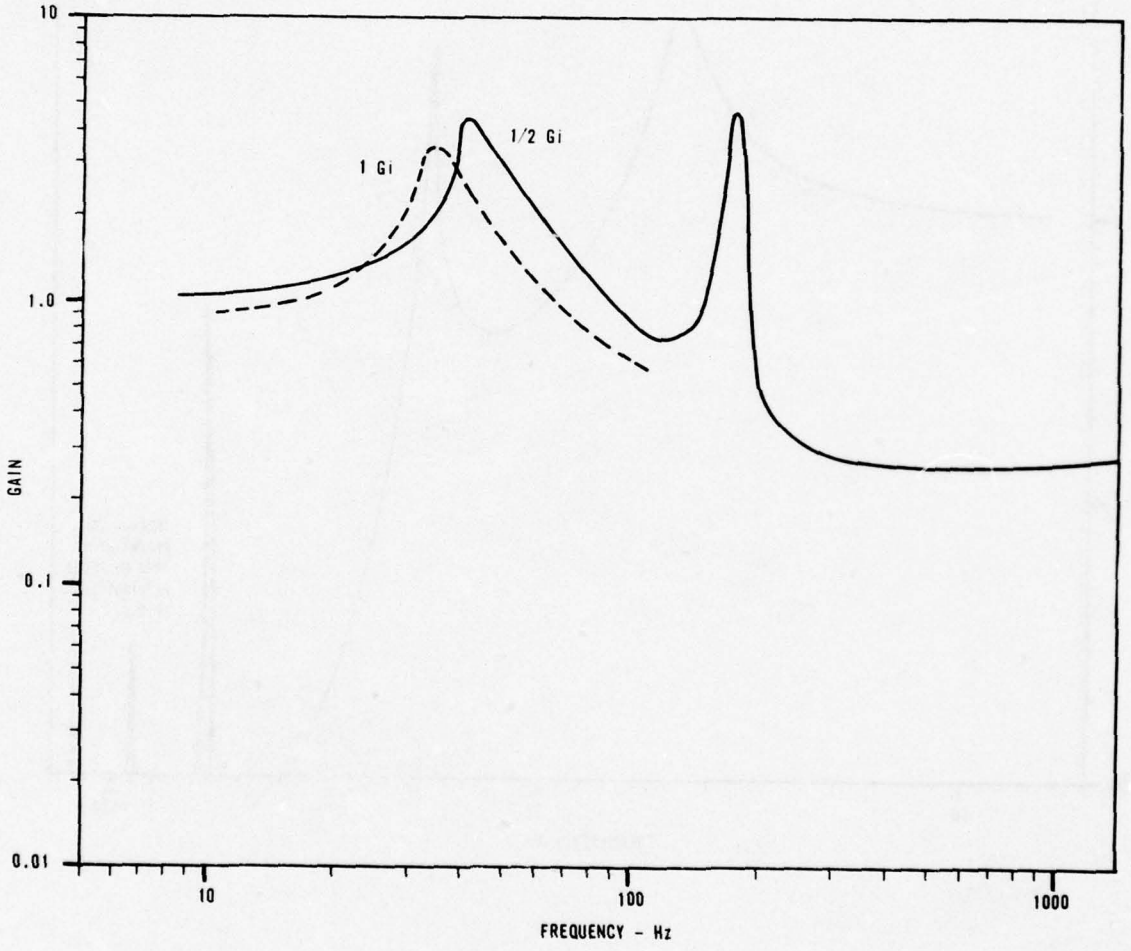


FIGURE 6.3.3-12. MEASURED TRANSFER FUNCTION, 40 Hz ISOLATORS, LATERAL

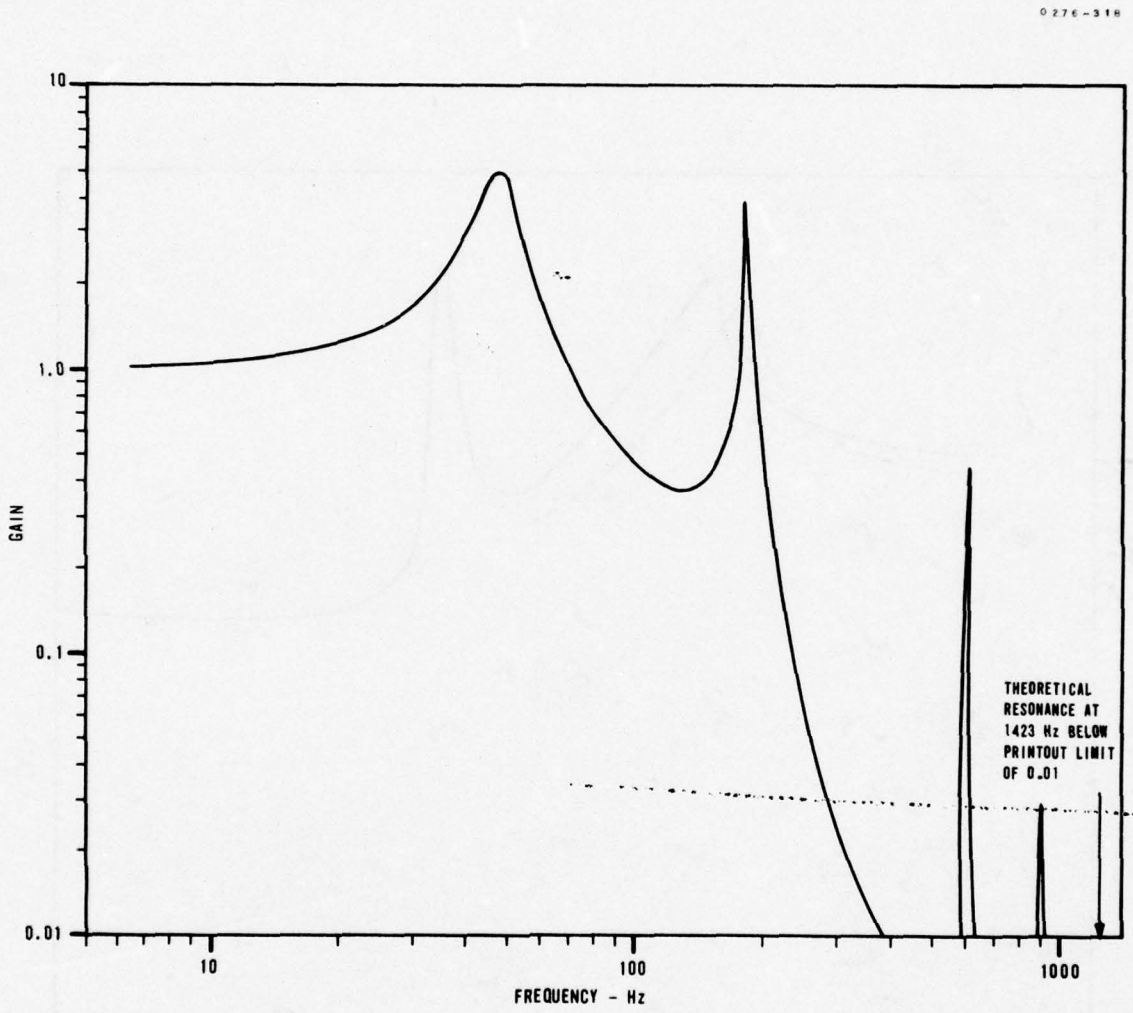


FIGURE 6.3.3-13. THEORETICAL TRANSFER FUNCTION, 40 Hz ISOLATORS, 5 SPRING-MASS-DAMPER MODEL WITH STRUCTURAL DAMPING

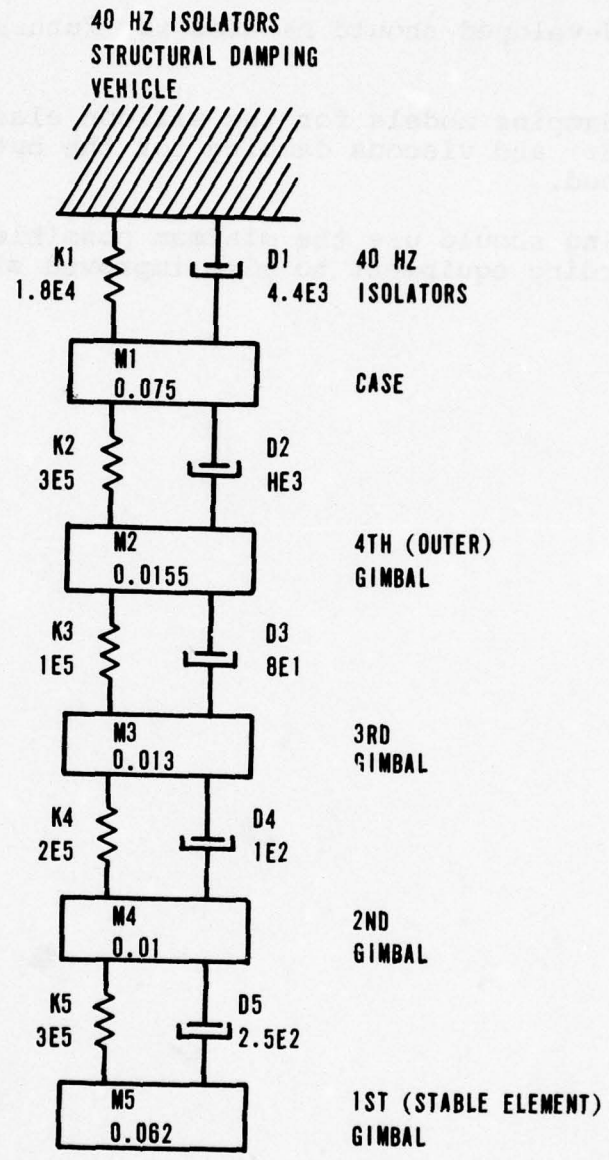


FIGURE 6.3.3-14. VIBRATION MODEL

6.4 TECHNICAL RECOMMENDATIONS

The models developed should be used for future shock and vibration simulations.

Structural damping models for the silicon elastomer isolators (16 and 40 Hz) and viscous damping for the butyl (35 Hz) isolators should be used.

Future testing should use the minimum possible full scale range of the recording equipment to give improved signal to noise levels.

Section 7

VIBRATION ISOLATOR STABILITY WITH TIME
(Ref. TCL No. 5)

Isolator defection as a function of time can be characterized as being between 10 percent and 15 percent of the static deflection/ decade of time. If d is the static deflection, we would expect to see:

(0.1 to 0.15) d sag in the first hour

2 x (0.1 to 0.15) d sag in the first 10 hours

3 x (0.1 - 0.15) d sag in the first 100 hours

etc.

The mismatch in sag can be as much as 20 percent. Then the difference in sag per decade of time could be as much as:

Δ = 0.1 (0.1 to 0.15) d

The static deflection of an isolator can be calculated as $d = \frac{10}{(f_r)^2}$

where d = static deflection in inches

and f_r = the resonant frequency of the isolato~ in Hz.

The resultant angular drift per decade of time, $\delta\theta$, is calculated as:

$\delta\theta = \frac{\Delta}{D}$ where D is distance between isolators in inches and $\delta\theta$ is the angular drift in radians.

Combining the above equations gives:

$$\delta\theta = \frac{(0.02 \text{ to } 0.03)\ 10}{14\ (f_r)^2} = \frac{0.0143 \text{ to } 0.0214}{(f_r)^2} \text{ rads}$$

for a 16 Hz isolator:

$\delta\theta_{16}$ = 11.5 to 17.2 arc-second per decade of time and a 40 Hz isolator gives:

$\delta\theta_{40}$ = 1.84 to 2.76 arc-second per decade of time

7.1 TEST DESCRIPTION

The purpose of this test was to measure the variation in movement between the isolators in a set of four 40 Hz isolators. Unmatched isolators were used in this test with simulated IMU masses. The weight of the dummy IMUs was selected at 2 x IMU weight to simulate a 2 g load. Two orientations were selected, vertical and horizontal. See Figures 7.1-1, 7.1-2, 7.1-3 and 7.1-4. Electronic levels with a resolution of one-half arc second were used to measure the angular movement in two orthogonal axis. See Figure 7.1-5 for diagram of orientations. The vertical test was begun seven days before the horizontal and each test was run 30 days.

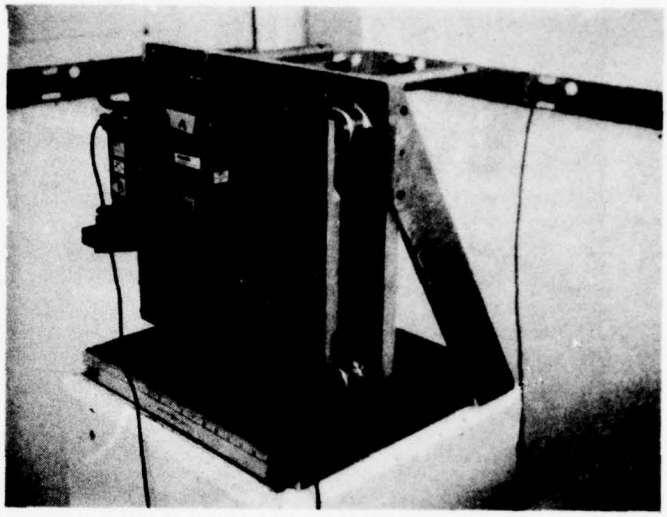


FIGURE 7.1-1. VERTICAL MODE

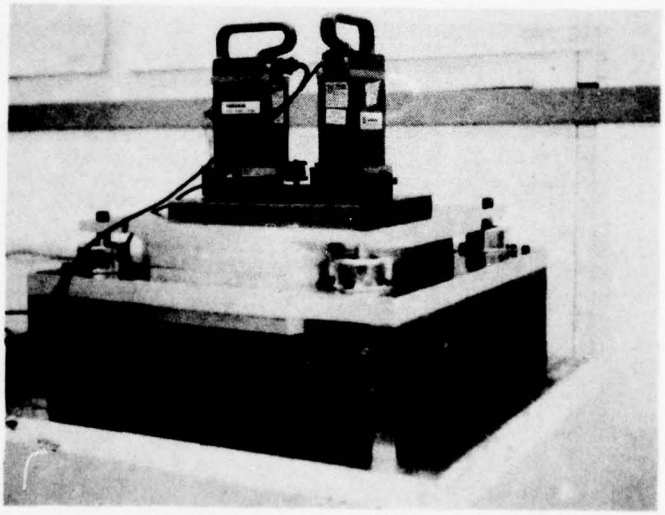


FIGURE 7.1-2. HORIZONTAL MODE

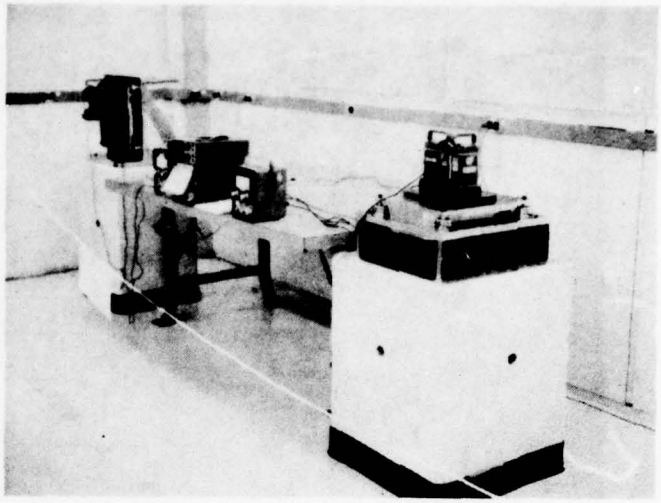


FIGURE 7.1-3. TEST PIERS

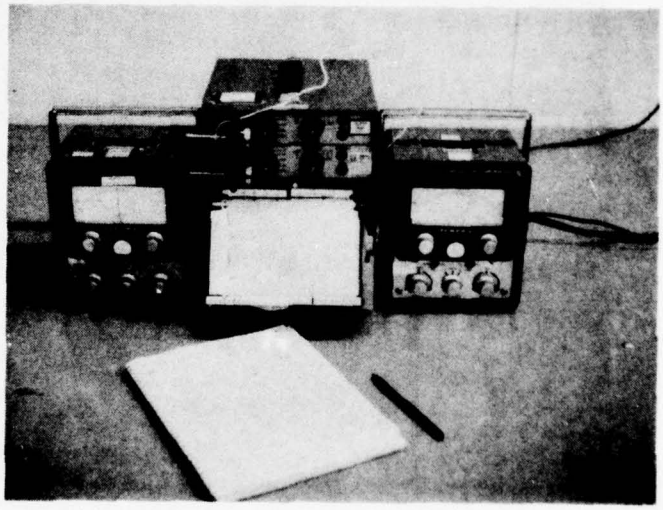


FIGURE 7.1-4. TEST INSTRUMENTATION

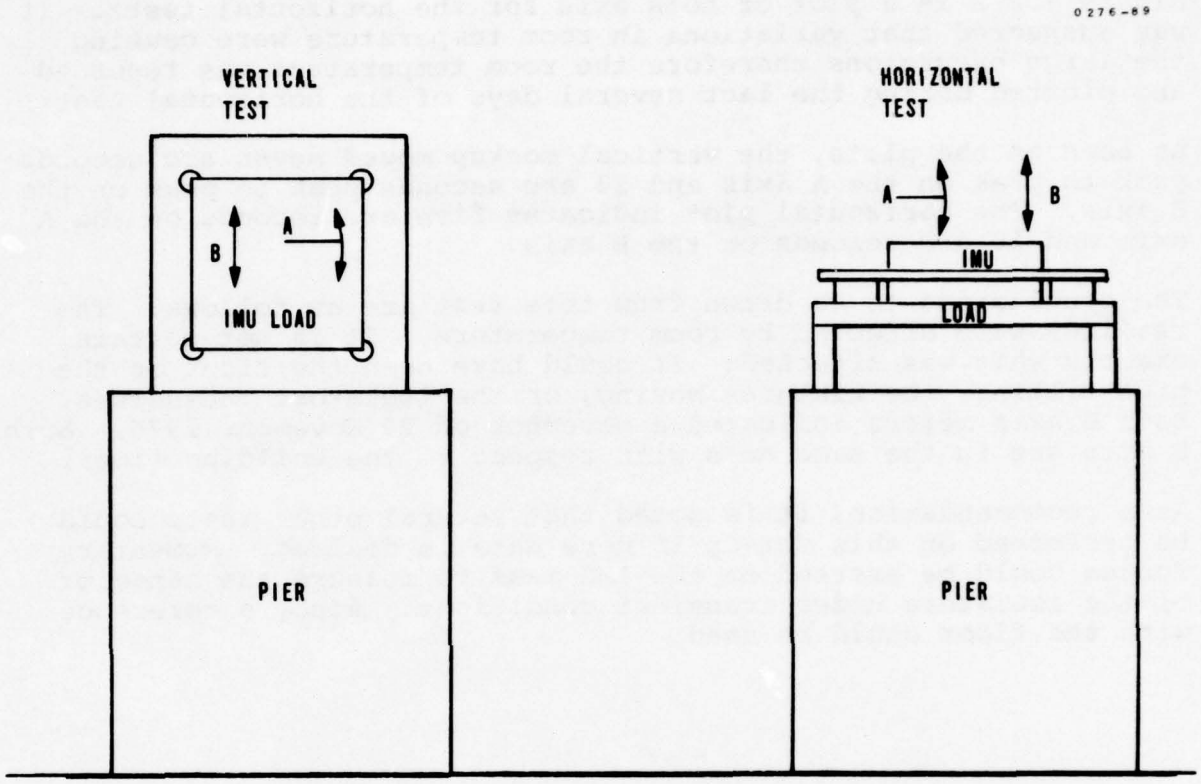


FIGURE 7.1-5. ISOLATOR TEST STANDS

7.2 TEST RESULTS

Daily readings were taken on each axis of each test and recorded. Figure 7.2-1 is a plot of the A and B levels on the vertical test. Figure 7.2-2 is a plot of both axis for the horizontal tests. It was suspected that variations in room temperature were causing the large excursions therefore the room temperature was recorded and plotted during the last several days of the horizontal test.

As seen on the plots, the vertical mockup moved seven arc seconds peak to peak on the A axis and 23 arc seconds peak to peak on the B axis. The horizontal plot indicates five arc seconds on the A axis and 10 arc seconds on the B axis.

The conclusions to be drawn from this test are as follows: The readings were affected by room temperature. It is not certain exactly what was affected. It could have been the floor or the pier tilting, the fixtures moving, or the isolators themselves. Both B axis meters indicated a movement on 24 November 1975. Both B axis are in the same axis with respect to the building floor.

As a recommendation, it is noted that several other tests could be performed on this set-up if more data is desired. Momentary forces could be exerted on the IMU mass to measure the behavior of the isolators under transient conditions. Also, a reference with the floor could be used.

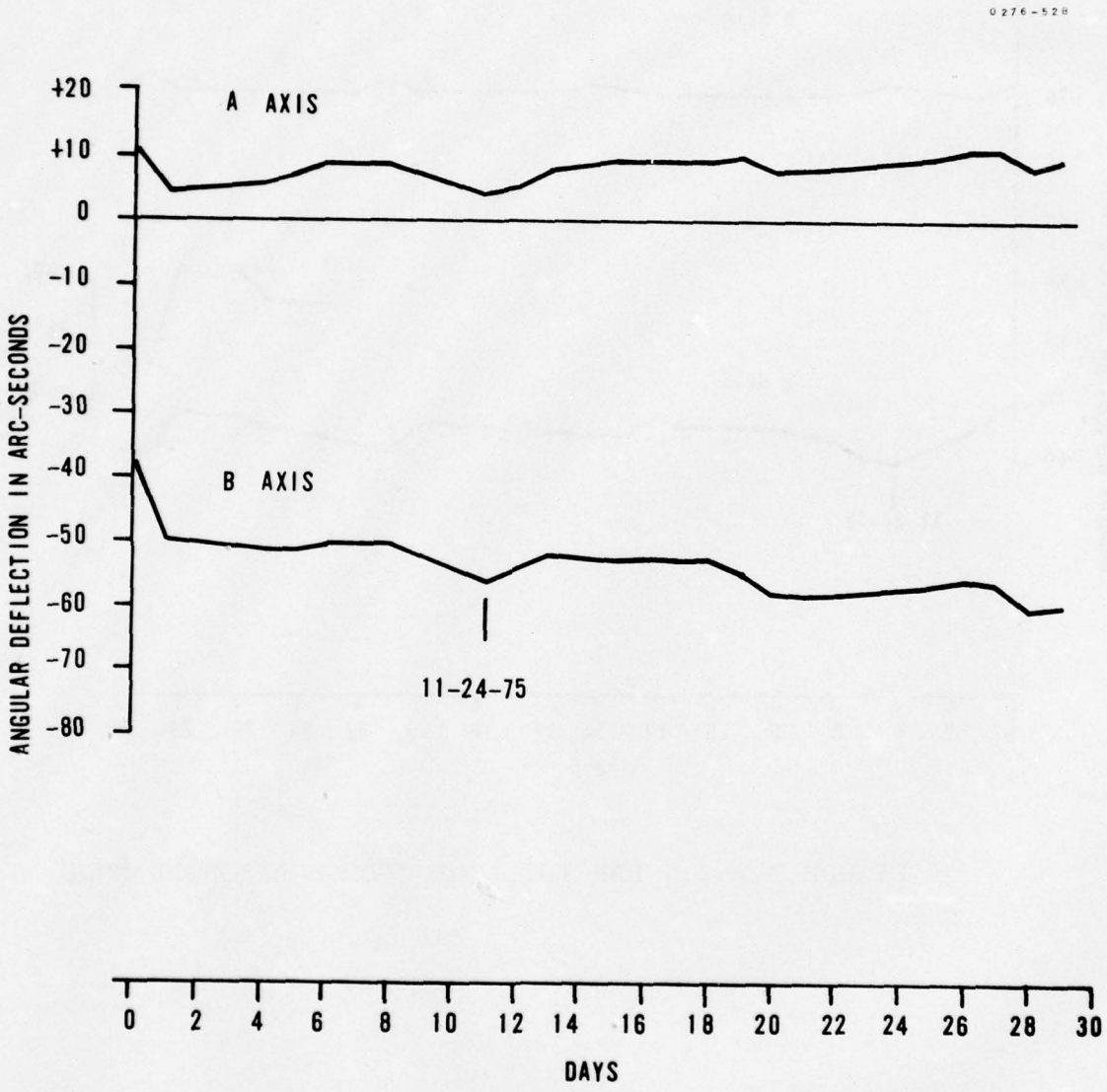


FIGURE 7.2-1. EAR ISOLATOR TEST VERTICAL MODE

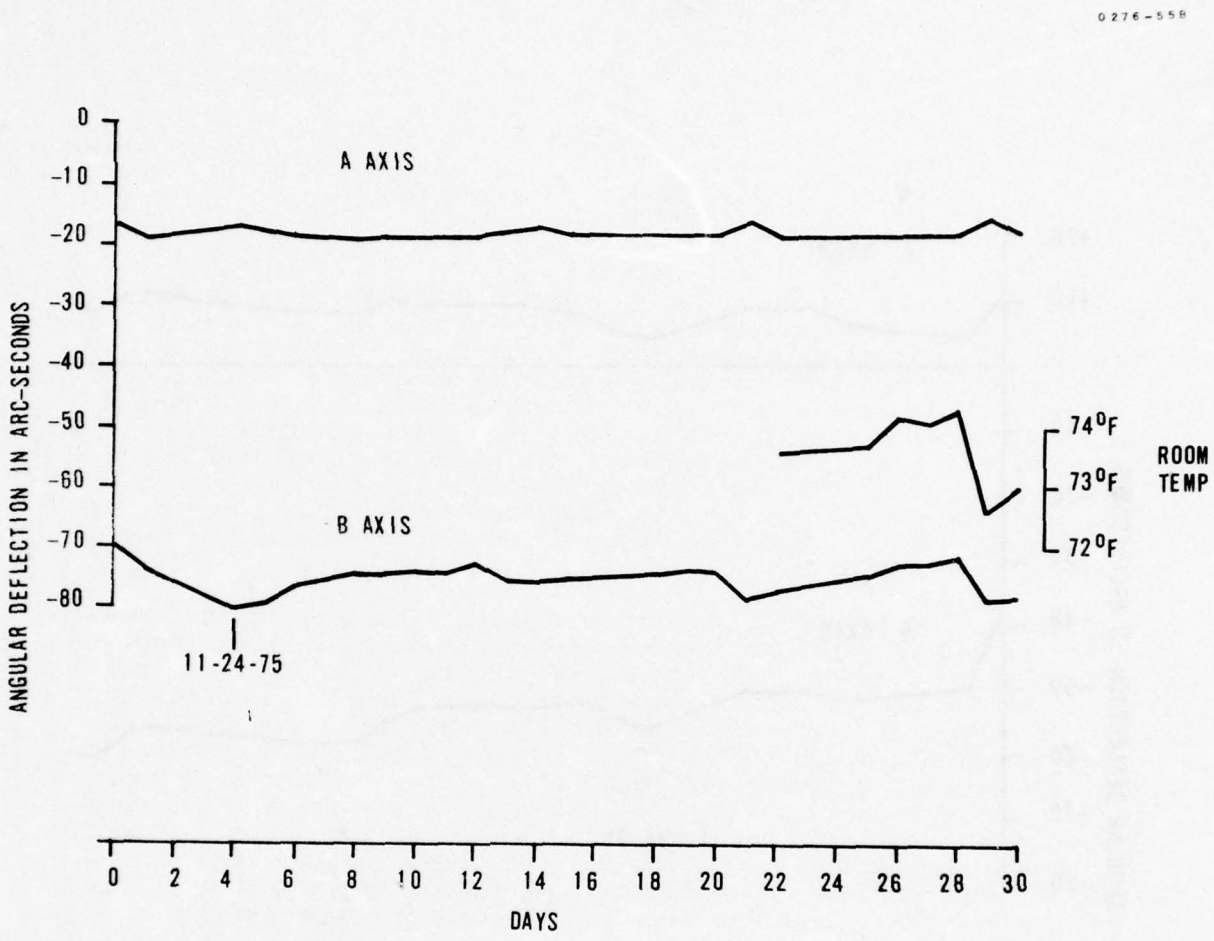


FIGURE 7.2-2. EAR ISOLATOR TEST HORIZONTAL MODE

Section 8

GIMBAL ANGLE READOUT ACCURACY (Ref. TCLs No. 1 and 3)

The potential accuracy of the SPN/GEANS gimbal angle readout is about equal to its quantization level-- 40 arc seconds peak to peak. This potential accuracy is obtained by using a single-speed pancake resolver having a specified accuracy of 360 arc seconds. The resolver has a set of compensation windings that are used to eliminate errors due to phase shift in the flux generated by the primary windings. All remaining resolver error terms are reduced to second order effects by phase detecting the two resolver outputs using orthogonal demodulator references (obtained from the phase-lock-loop counter) and summing the two phase detector outputs.

The measured error of one resolver (having a tangent bridge measured error of 150 arc seconds, tested with just one phase-lock-loop operating in a quiet environment) was 40 arc seconds peak-to-peak. Tests on the same resolver with three phase-lock-loops operating showed errors of 116 to 146 arc seconds peak-peak. Averaging of the individual errors of the three loops reduced the error spread to 20 arc seconds peak-peak, suggesting the error increase was due to noise/cross-coupling of the loops. Analysis of the errors showed no predominant harmonic error in any of the loops; indicating the loops were indeed canceling out the predominant second and fourth harmonics errors measured in the resolver, and that the resulting phase-lock-loop errors were probably caused by noise/cross-coupling.

Several design modifications have been incorporated in the SPN/GEANS circuitry to minimize the noise/cross-coupling sensitivity. These include:

1. Replacement of the phase-lock-loop R-C oscillator with an LC type-- reducing the noise bandwidth by better than 10:1 and thereby reducing readout jitter due to internal and external noise.

2. Use of a 4X faster switching phase detector to reduce deadband.

3. Addition of anti-coincidence circuitry in the readout strobe signal.

4. Addition of an op-amp hash filter to eliminate voltage rate saturation.

5. Rerouting of power slip ring paths so that both the input and return lines pass through the center of the resolver.

Initial bench tests on circuitry with the above modifications indicate that loop noise/cross-talk has been reduced to below the quantization level.

Error plots for 21 SPN/GEANS type resolvers, using conventional tangent-bridge readout, were analyzed. By selectively removing the predominant harmonic errors from this data, an indication of the potential phase-lock-loop accuracy can be obtained. Figure 8.0-1 presents histograms of peak to peak errors of these units, for the following conditions:

1. The raw error data

2. With the second harmonic error removed (the predominant error in all the resolvers)

3. With the second and the next most significant harmonics removed from the five worst resolvers.

The results are summarized in the Table 8.0-1.

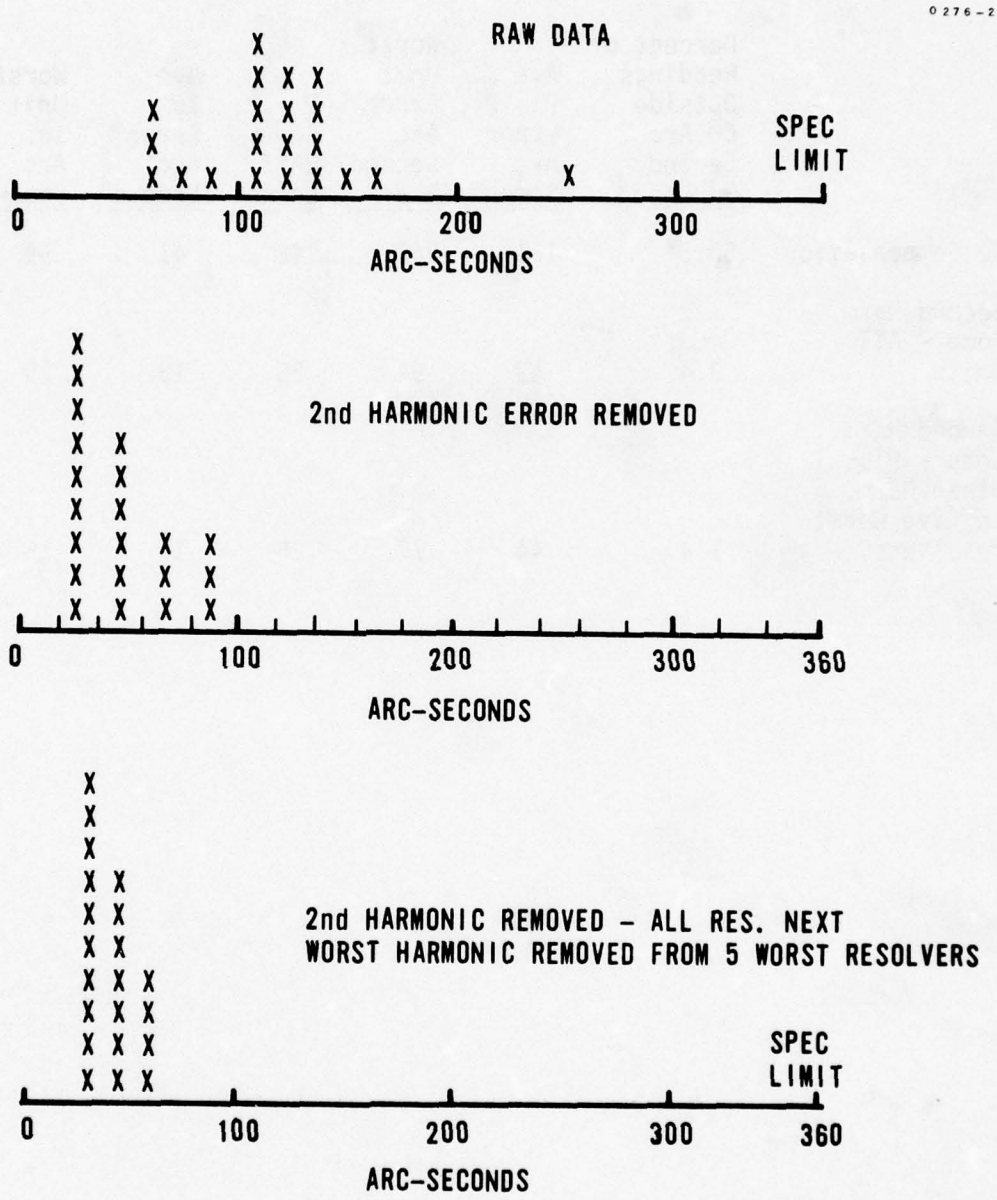


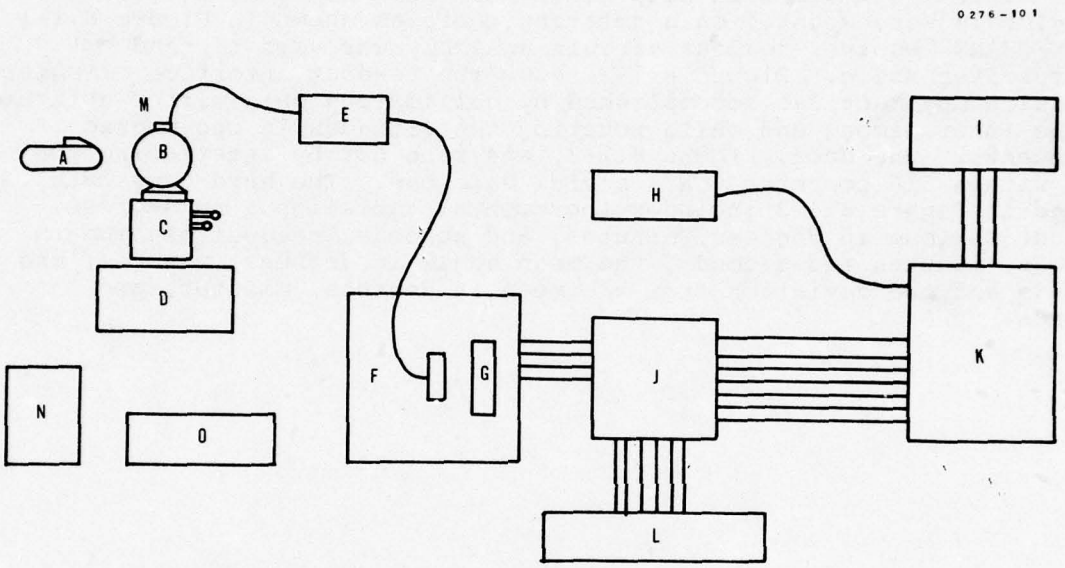
FIGURE 8.0-1. HISTOGRAM OF RESOLVER ERRORS USING TANGENT BRIDGE READOUT

TABLE 8.0-1. SUMMARY OF RESOLVER ERRORS USING TANGENT BRIDGE READOUT

	Percent of Readings Outside 60 Arc Second Spread	Ave P - P Error Arc Second	Worst Unit Error Arc Second P - P	P - P Best Unit Error	Ave 1σ Error Arc Second	Worst Unit 1σ Arc Second	Best Unit 1σ Arc Second
No Compensation	50.5	131	262	42	41	99	12
Second Harm. Comp - All Units	3.4	49	94	25	13	25	7
Second Harm. Comp - Plus 1 other Harm. in five worst resolvers	1.4	44	77	25	11	18	7

8.1 TEST DESCRIPTION

In order to gain more knowledge about the nature of the noise in the resolver readout circuits, a single resolver mock-up was constructed. A set of test gimbals with slip rings were used to mount a resolver. The gimbals were mounted on a rotating table as shown in Figure 8.1-1 A SPN/GEANS resolver readout circuit assembly was used to read out the resolver angle. Figure 8.1-2 shows the readout interface circuitry. Precision movement was accomplished by collimating on a mirror attached to the inner gimbal and while rotating the ultradex in one-degree increments. The data, Figure 8.1-3, was read out by interfacing the loop with a 516 computer via a serial data bus. The hard copy data listed in Figure 8.1-3 includes incremental table input in degrees, readout maximum in degrees, minutes, and seconds, readout minimum in degrees, minutes and seconds, the mean angle in degrees, minutes, and seconds and the deviation from the mean in degrees, minutes, and seconds.



A - AUTO COLLIMATOR HON NO. 600-035
ON STAND HON NO. CG 1575-13

B - GIMBALS

C - DIVIDER HEAD ULTRADEX SN 7098

D - PRATT AND WHITNEY TABLE HON NO. 500-14

E - 34021216 MODIFIED (GIMBAL LOOP ELECTRONICS)

F - ESG GEN AND DIGITAL TEST FIXTURE 180487

G - R/D BOARD 34021212

H - PULSE GEN EH139B HON NO. 322-588

I - TELETYPE

J - GIMBAL ANGLE READOUT INTERFACE

K - COMPUTER DDP 1516R HON NO. 3651-5

L - LIGHT READOUT BOX

M - D.U.T.

N - POWER SUPPLY, POWER DESIGNS TW5005, HON NO. 280-869
±15 VDC

O - POWER SUPPLY TYGONM15-10, +5 VDC

FIGURE 8.1-1. DIAGRAM OF GIMBAL MOUNT ON ROTATION TABLE

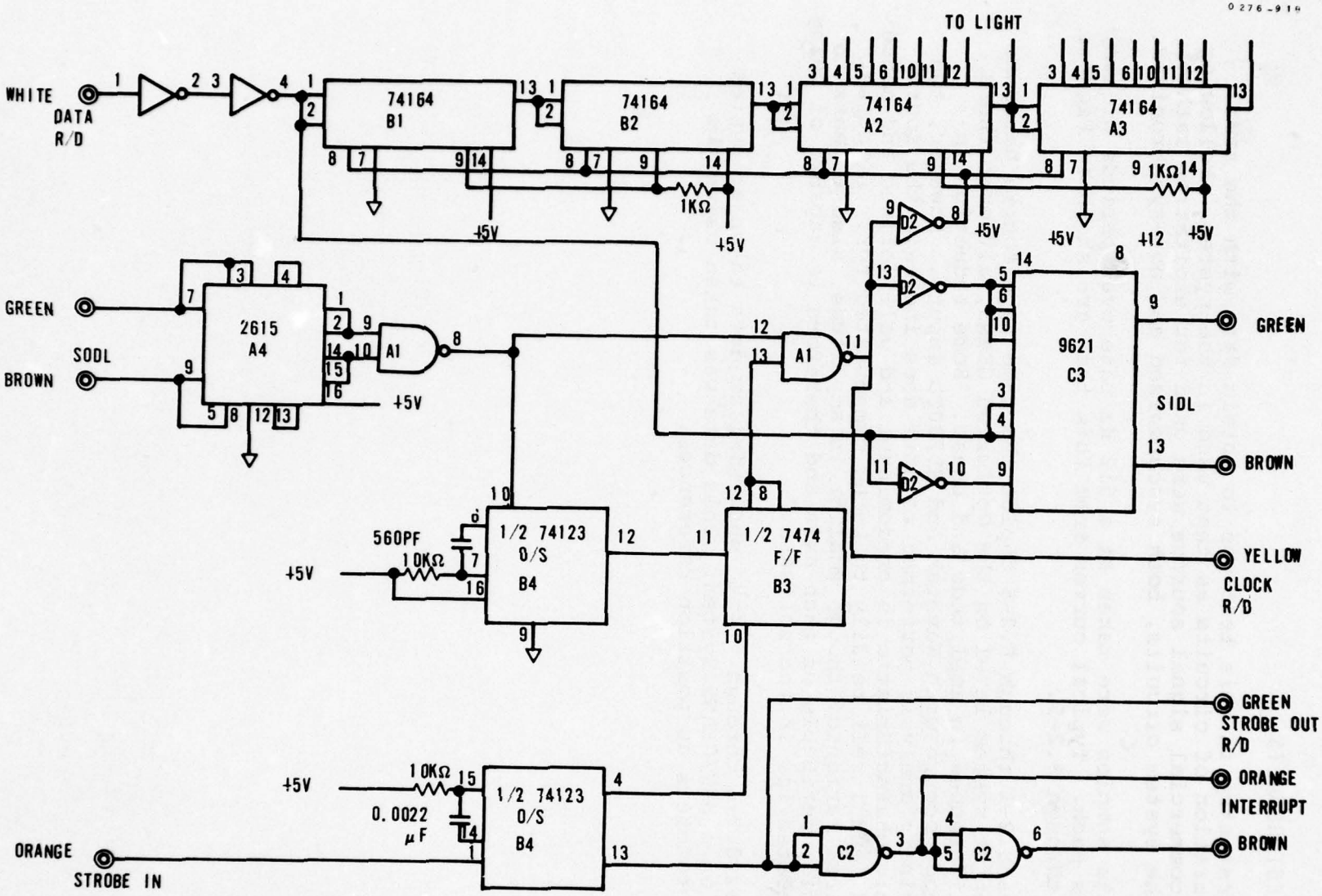


FIGURE 8.1-2. GIMBAL ANGLE READOUT INTERFACE

8.2 TEST RESULTS

The first step in this test was to obtain data with the same configuration of circuits as that used in the system. Following this, commercial signal sources were used for excitation rather than the system circuits, both synchronized and non-synchronized.

The data samples were taken at a 512 Hz rate over periods of two seconds each. Typical curves from this test are shown in Figures 8.2-1 through 8.2-5.

Figures 8.2-1 through 8.2-5 depict the same type fourth harmonic as seen at system level on the Optimized GEANS, although there are differences in amplitude and phase. Some reduction in amplitude occurs with Wavetek and HP200CD inputs. However, the preliminary analysis performed to date does indicate the fourth harmonic characteristic is predominant and well defined and hence should lend itself readily to being compensated for. Likewise, the first harmonic, though smaller in amplitude, also appears to be easily definable on each axis and therefore is capable of being compensated for in the software.

Figures 8.2-6 through 8.2-9 show similar data taken at system level on a SPN/GEANS System. This data was taken using the accelerometers as position references.

Table Input	Readout, Maximum			Readout, Minimum			Mean Angle			Deviation From Mean Angle		
Degrees	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds
1	75	39	46.230	75	34	29.824	75	37	21.595	0	0	48.007
1	65	39	15.469	65	34	38.613	65	36	57.700	0	0	43.867
1	55	39	24.258	55	34	47.402	55	37	18.766	0	0	43.810
1	45	40	12.598	45	36	15.293	45	38	25.811	0	0	43.187
1	35	41	40.488	35	37	43.184	35	39	52.987	0	0	42.302
1	25	43	8.379	25	38	31.523	25	40	59.413	0	0	45.512
1	15	43	17.168	15	38	0.762	15	40	47.967	0	0	45.412
1	5	42	6.855	5	38	9.551	5	40	18.487	0	0	43.914
1	355	41	36.094	355	37	38.789	355	39	11.733	0	0	40.703
1	345	40	25.781	345	36	28.477	345	38	23.613	0	0	41.156
1	335	39	55.020	335	35	57.715	335	38	8.672	0	0	40.714
1	325	40	3.809	325	36	6.504	325	38	25.371	0	0	39.931
1	315	41	31.699	315	37	34.395	315	39	28.213	0	0	41.296
1	295	44	27.480	295	39	11.074	295	42	8.394	0	0	46.735
1	285	43	56.719	285	39	19.863	285	41	54.111	0	0	47.217
1	275	43	25.957	275	38	49.102	275	41	6.870	0	0	45.744
1	265	42	15.645	265	37	38.789	265	39	48.867	0	0	42.616
1	255	41	5.332	255	35	48.926	255	38	50.420	0	0	49.434
1	245	40	34.570	245	35	18.164	245	38	7.134	0	0	48.040
1	235	40	3.809	235	35	26.953	235	38	3.179	0	0	46.136
1	225	41	31.699	225	36	15.293	225	38	55.698	0	0	43.993
1	215	42	20.039	215	37	43.184	215	40	14.795	0	0	41.608
1	205	43	8.379	205	38	31.523	205	41	7.090	0	0	44.900
1	195	43	17.168	195	38	0.762	195	40	41.272	0	0	48.667
1	185	42	6.855	185	37	30.000	185	39	53.042	0	0	45.508
1	175	40	56.543	175	36	19.688	175	38	45.586	0	0	41.761
1	165	39	46.230	165	35	9.375	165	37	34.175	0	0	44.105
1	155	39	15.469	155	34	38.613	155	36	57.041	0	0	46.509
1	145	39	24.258	145	34	47.402	145	37	12.751	0	0	47.173
1	135	40	12.598	135	36	15.293	135	38	8.562	0	0	43.582
1	125	41	40.488	125	37	3.633	125	39	35.244	0	0	47.244
1	115	42	28.828	115	38	31.523	115	40	29.022	0	0	46.032
1	105	43	17.168	105	38	0.762	105	40	21.057	0	0	49.865
1	95	42	6.855	95	36	50.449	95	39	37.222	0	0	44.800
1	85	40	56.543	85	36	19.688	85	38	33.501	0	0	45.010
1	75	40	25.781	75	35	9.375	75	37	41.536	0	0	46.905
1	58	34	44.766	56	49	16.641	57	27	41.329	0	38	49.949

FIGURE 8.1-3. TYPICAL DATA OUTPUT

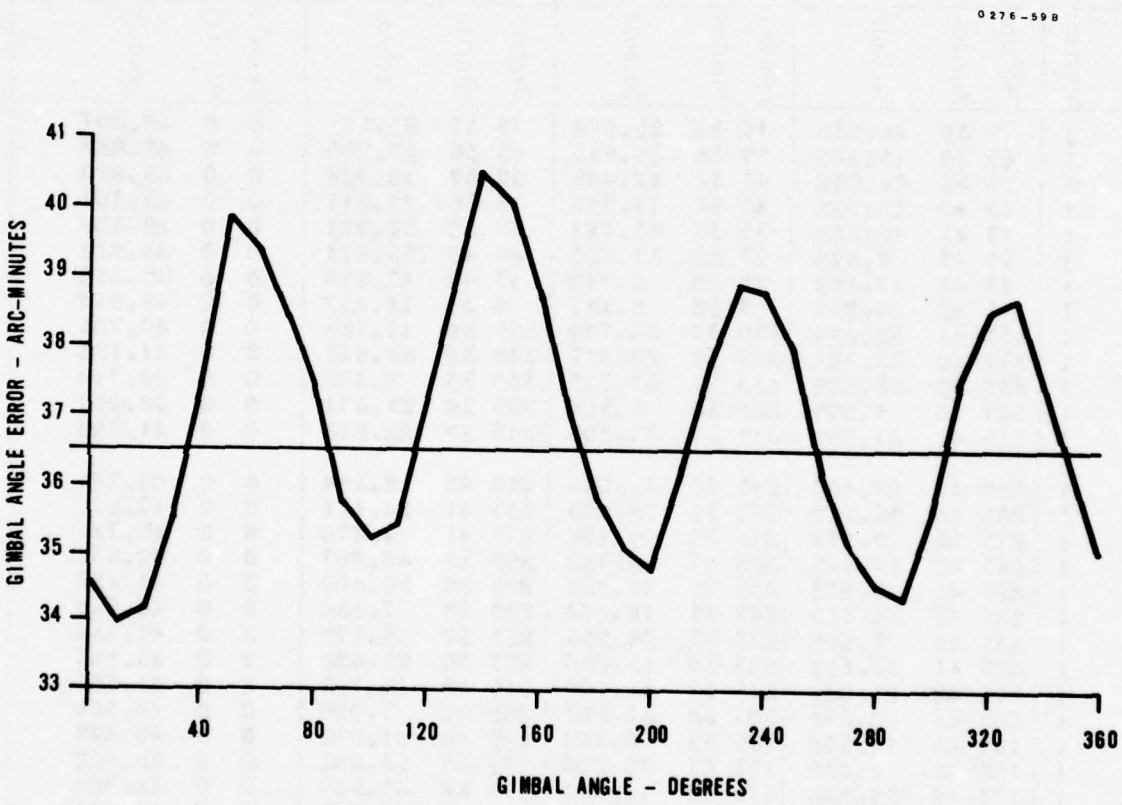


FIGURE 8.2-1. SPN GIMBAL ANGLE ACCURACY-LOOP 2 (SYSTEM EXCITATION)

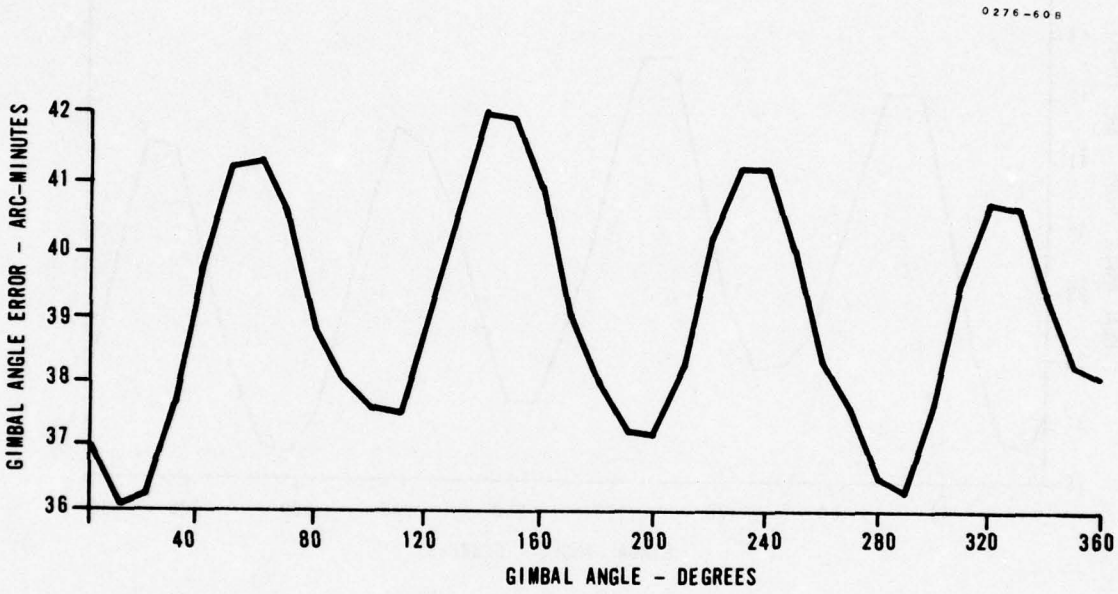


FIGURE 8.2-2. SPN GIMBAL ANGLE ACCURACY-LOOP 4 (SYSTEM EXCITATION)

0276-97

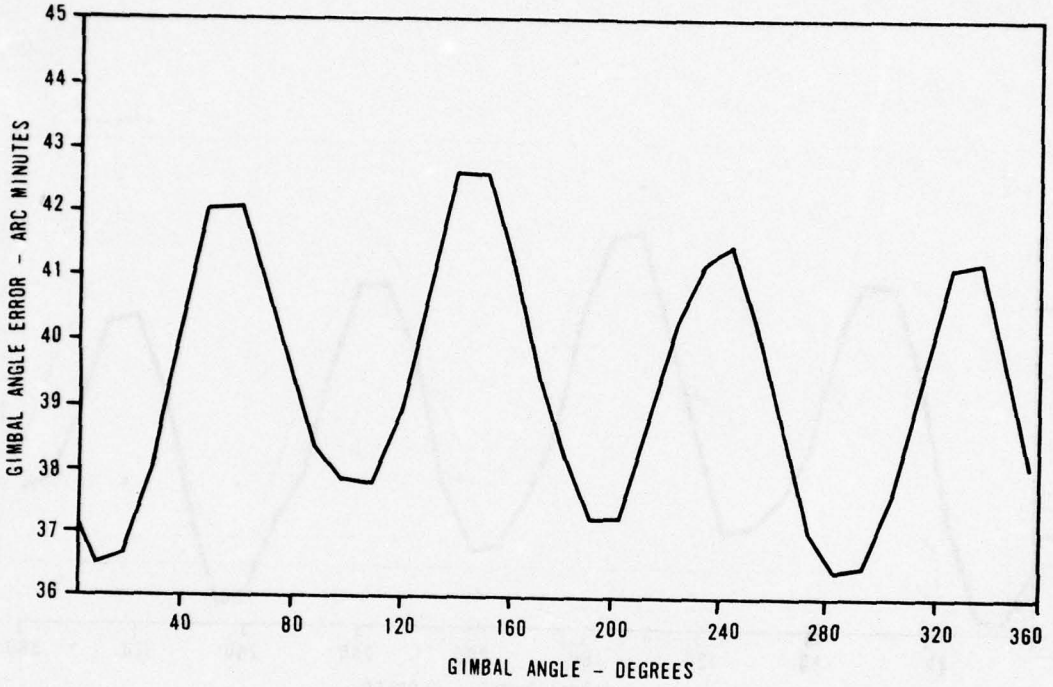


FIGURE 8.2-3. SPN GIMBAL ANGLE ACCURACY-LOOP 3 (SYSTEM EXCITATION)

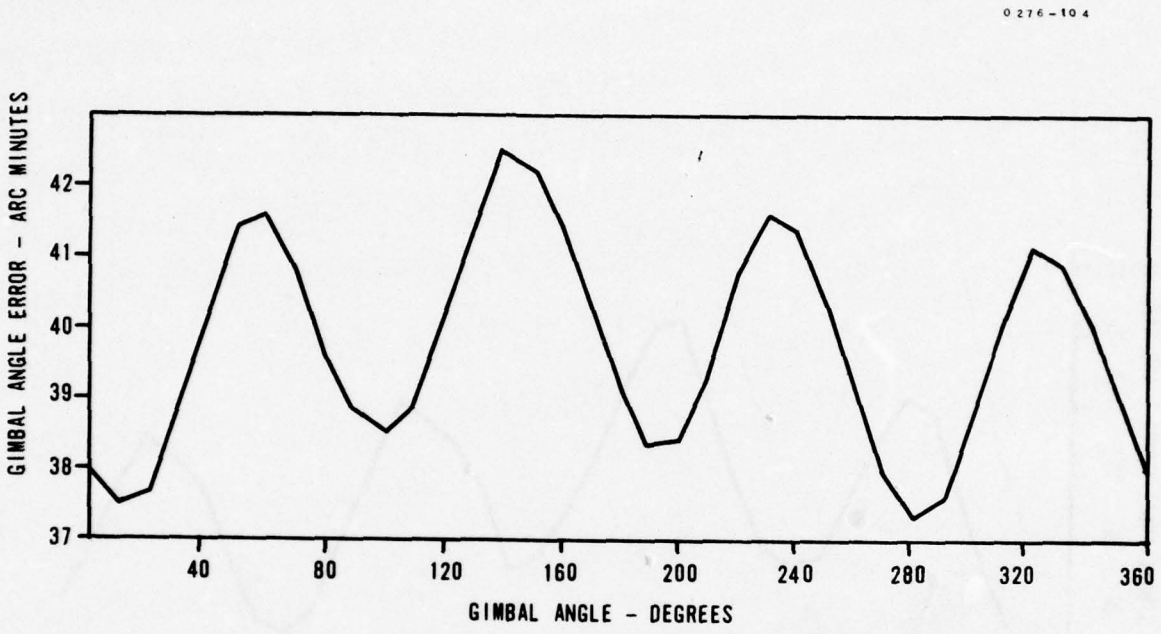


FIGURE 8.2-4. SPN GIMBAL ANGLE ACCURACY-LOOP 3
(WAVETEK P.S. EXCITATION INPUT)

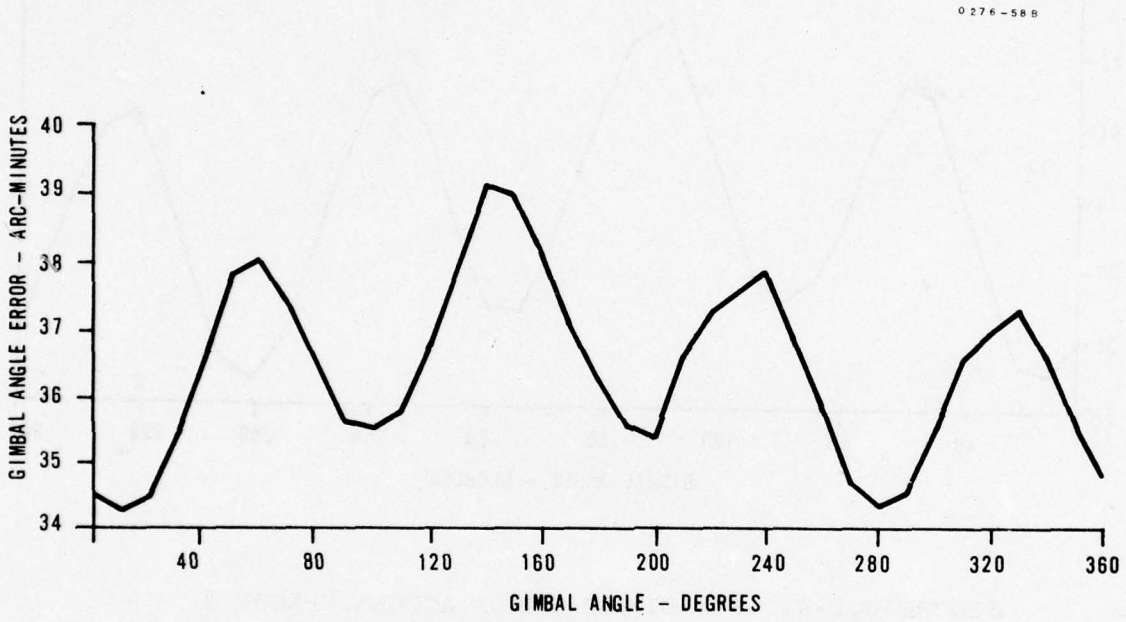


FIGURE 8.2-5. SPN GIMBAL ANGLE ACCURACY-LOOP 3
(HP200CD P.S. EXCITATION INPUT)

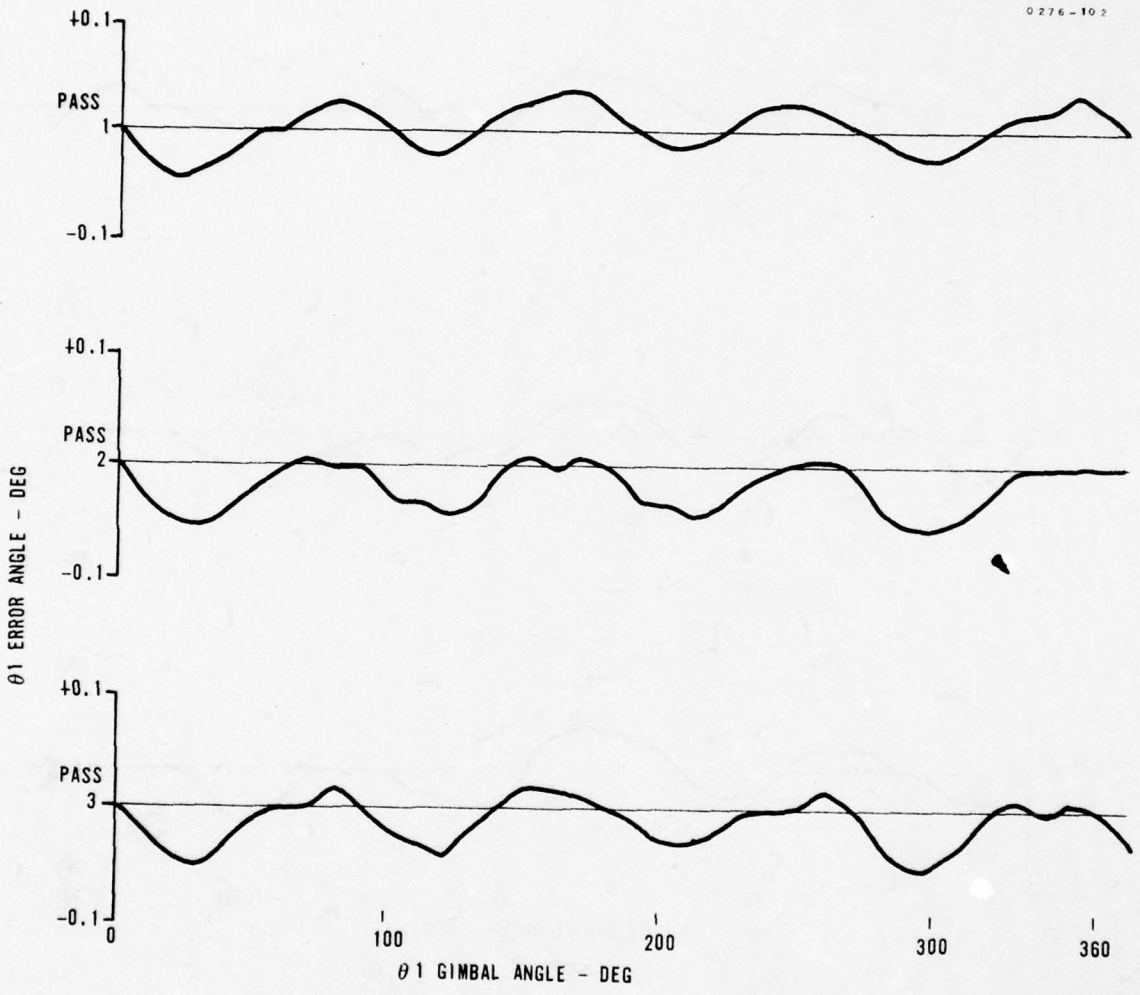


FIGURE 8.2-6. GIMBAL NO. 1 ACCURACY DATA

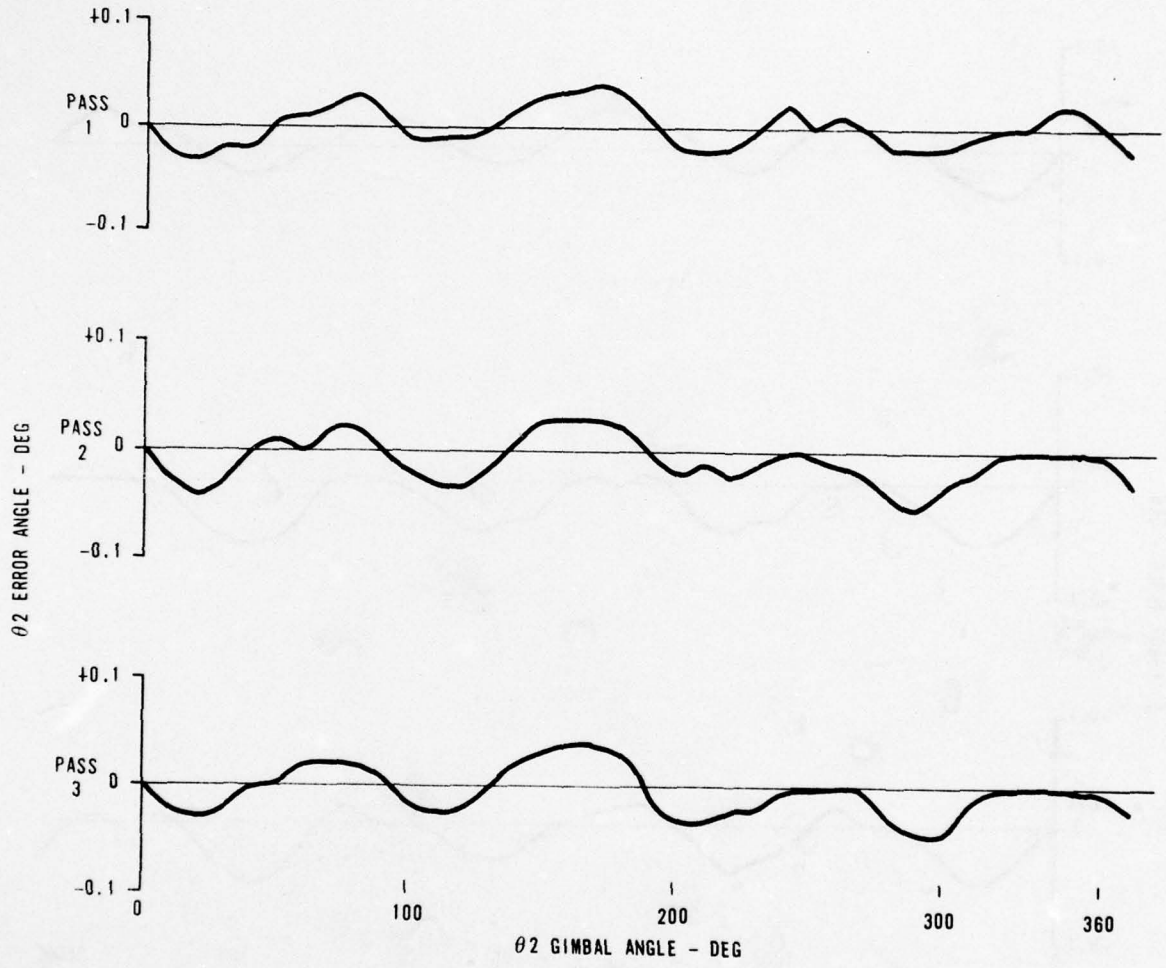


FIGURE 8.2-7. GIMBAL NO. 2 ACCURACY DATA

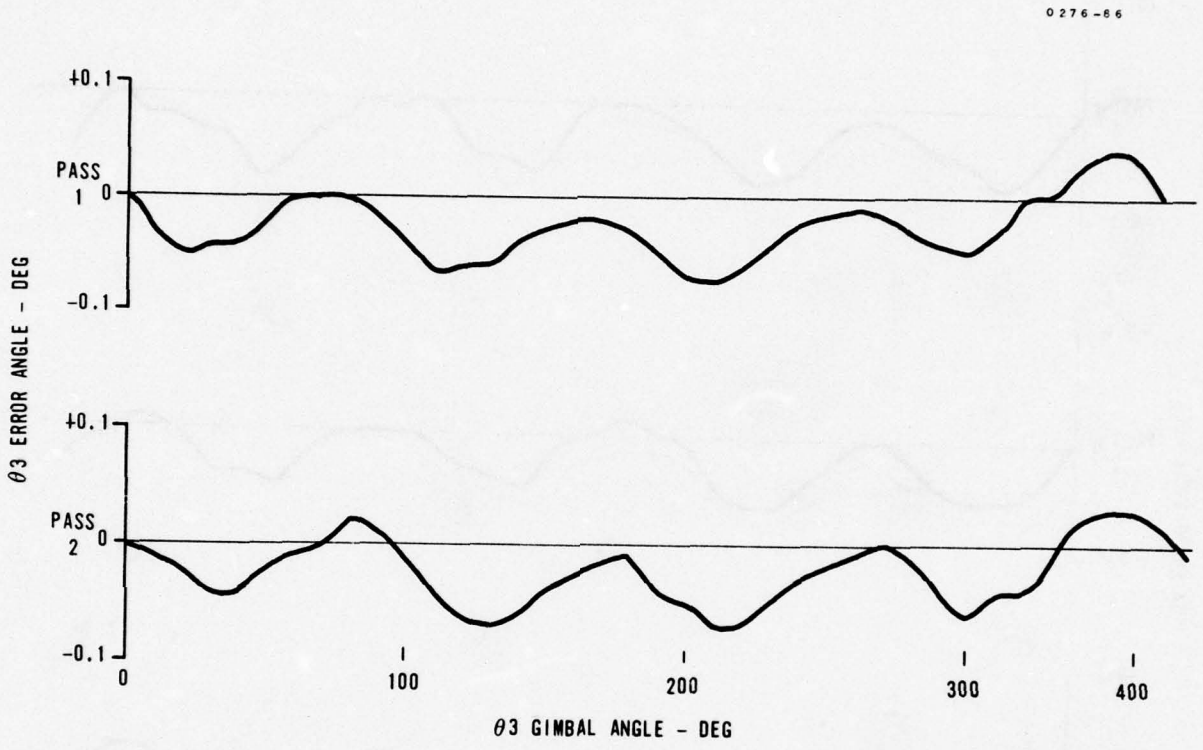


FIGURE 8.2-8. GIMBAL NO. 3 ACCURACY DATA

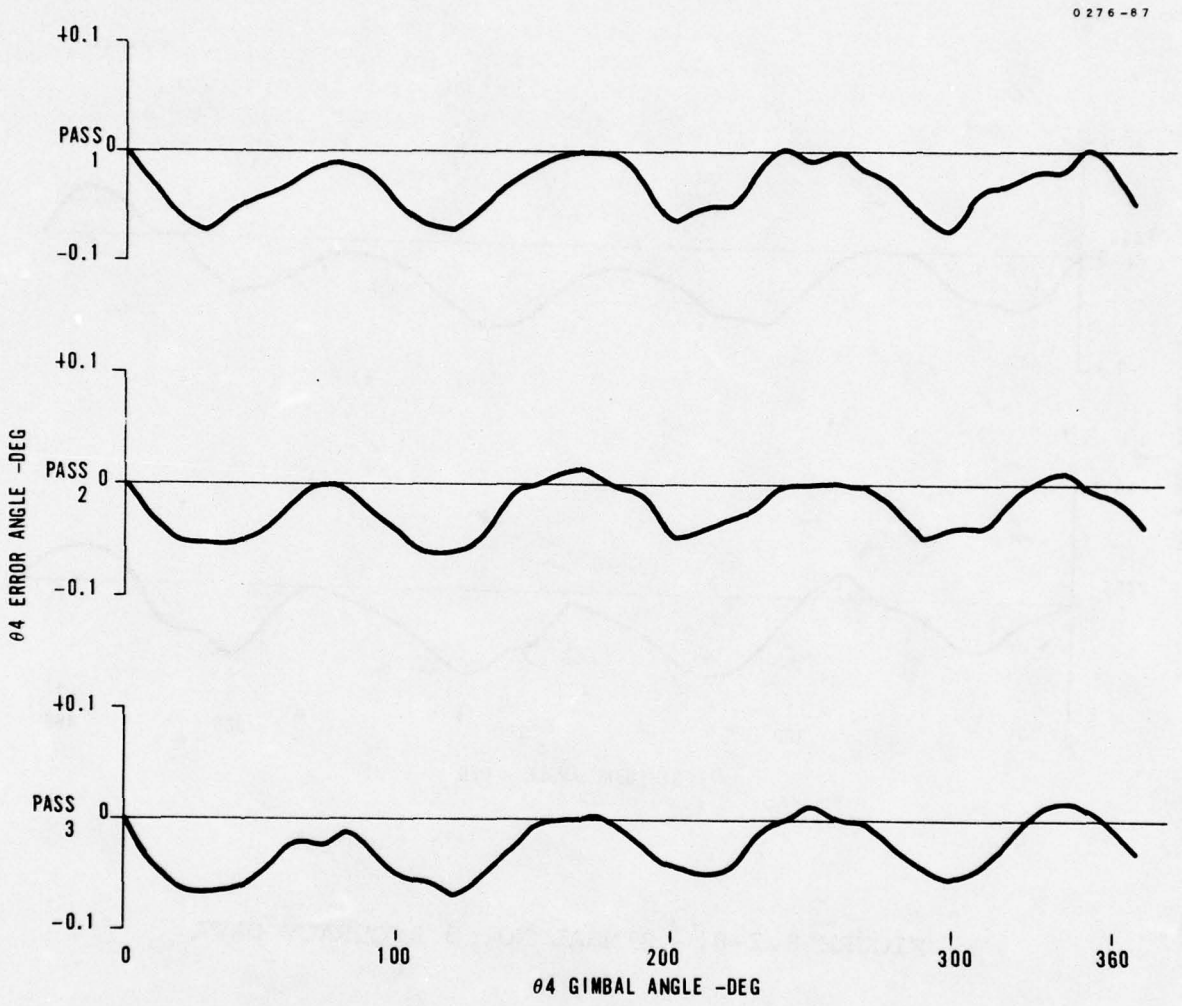


FIGURE 8.2-9. GIMBAL NO. 4 ACCURACY DATA

8.3 TECHNICAL RECOMMENDATIONS

Data taken at all levels demonstrates the periodicity and repeatability of the gimbal angle harmonic errors and this serves as the basis for Honeywell recommending use of a software compensation scheme. This can be readily implemented as a modification to the current ARC calibration program used with the SPN system. Software compensation appears to offer a more direct and less costly solution to gimbal angle readout errors than does an extended investigation into the hardware characteristics and error sources and probable subsequent hardware modifications.

Section 9

ADDITIONAL DESIGN DATA

Information in several technical areas supplied to date by Technical Coordination Letters is summarized in the following paragraphs. In addition, the results of measurements and calculations of accelerometer non-linearity due to torque generator reaction torque are reported. These measurements were made as a result of the early loop non-linearity data, which showed some parameters larger than expected.

Other items of design data were provided during the study at the Preliminary Design Review (PDR) and at technical coordination meetings.

Certain other items of data have been requested during the study but are not yet available. They include:

1. Inertial sensor parameter shifts as a function of vibration (ref. PDR)

2. Attitude accuracy data under dynamic conditions (ref. PDR)

3. Predicted performance envelope using EAR and SPN/GEANS for in-air start and alignment (zero ground reaction time).

Providing some of these require tasks beyond the scope of the original study and hence should receive further consideration.

Questions that were answered informally during the course of the study to-date included:

1. Use of cable isolators. Determined not feasible because of high frequency transmissibility near gimbal resonance, etc.

2. Vertical versus horizontal mounting of the IMU. Horizontal mounting is required to obtain the designed internal airflow and hence full rated performance (without heading sensitivity) An alternative would be a hardware design change for airflow.

9.1 IMPACT OF 16 HZ DATA RATE BETWEEN COMPUTER AND IEU (Ref. TCL No.2)

The suggested 16 Hz data rate impacts two areas, the ΔV storage capacity required and stability of the gimbal loops when under computer control, when compared with the current 32 Hz SPN/GEANS mechanization.

The ΔV storage capacity must be increased by a factor of two with the lower data transfer rate. This is a straight-forward mechanization change that can be done in either the IMU or the IEU, depending upon available packaging space.

The stability of the gimbal loops when under computer control (this occurs only during gyro spin-up) is affected by the time lag due to sampling the data once each computation cycle and by the time lag due to the delay in issuing a command after the data is sampled.

Sufficient phase margin exists in the present SPN/GEANS mechanization to handle the 16 Hz sampling rate if the command delay after sampling is less than 0.003 second. Command delays of up to 1/64 second can be tolerated by a minor modification of the computer program that would permit different frequency compensation terms for each gimbal loop. Table 9.1-1 compares the loop phase margins for the various combinations of sample rates, delay and compensation

TABLE 9.1-1. LOOP PHASE MARGIN VERSUS SAMPLE RATE, LAG TIME AND COMPENSATION CORNERS

Comp Cycle Rate		Compensation Freq. of max ϕ lead-rads/second Gimbal Number				Phase Margins - Degree Gimbal Number			
Hz	Second Delay	1	2	3	4	1	2	3	4
32	0	13	13	13	13	12	16	18	19
16	0	13	13	13	12	6	6	8	11
16	1/64	4	6	7	9	19	14	11	8

An alternate approach to stabilization is to close a "fast" loop from gimbal pickoff to torque motor in the hardware with the computer supplying command inputs to this loop. Figure 9.1-1 is a functional block diagram of such a loop. The computer command word input rate is converted to a series of incremental angle changes during each computation cycle. These command increments are summed with incremental gimbal angles in an accumulator to generate a whole angle error signal which is converted to dc, frequency compensated, amplified, and sent to the torquer to null the error signal. The cost of this approach in terms of hardware is 12 resistors, 4 capacitors, and 32 flat packs (assuming a four-bit register/adder per flat pack). This circuitry would probably be packaged in the SPN/GEANS IMU Electronics.

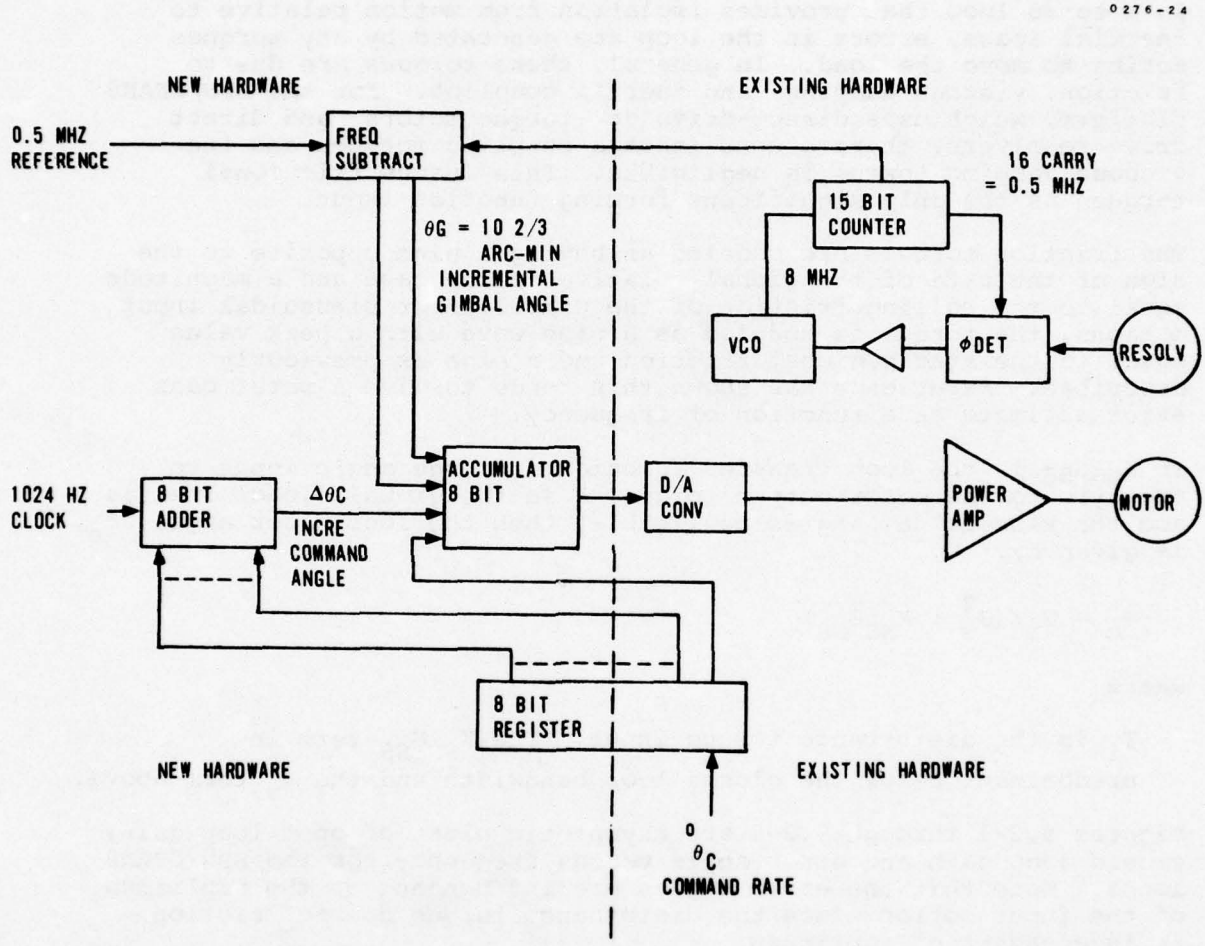


FIGURE 9.1-1. PROCESSOR MECHANIZATION

9.2 GIMBAL SERVO ERRORS (Ref. TCL NO. 4)

In a servo loop that provides isolation from motion relative to inertial space, errors in the loop are generated by any torques acting to move the load. In general, these torques are due to friction, viscous damping, and inertia coupling. For the SPN/GEANS platform, which uses direct-drive dc torque motors and direct drive resolvers, there are no inertia coupling torques and the viscous damping torque is negligible. This leaves frictional torques as the only significant forcing function input.

The friction torques are modeled as having a sign opposite to the sign of the rate of the gimbal relative to the case and a magnitude equal to the rolling friction of the gimbal. For sinusoidal input motions, the torque is modeled as a sine wave with a peak value equal to the static gimbal friction and a sign as previously described. Experience has shown this tends to give a worst case error estimate as a function of frequency.

If $K_{SS}G_{SS}$ is the loop transfer fucntion from the angle input to the gyro to the motor output torque, J is the gimbal (load) inertia and the viscous damping is negligible, then the loop error angle, θ_e, is given by:

$$\theta_e = T_i/(J_s^2 + K_{SS}G_{SS})$$

where

T_i is the disturbance torque input. The $K_{SS}G_{SS}$ term in predominant below the closed loop bandwidth and the J_s^2 term above.

Figures 9.2-1 through 9.2-3 are asymptotic plots of open loop gain, closed loop gain and error angle versus frequency for the SPN/GEANS loops. Note that the error angles are independent of the amplitude of the input motion since the disturbance torque due to friction is independent of amplitude.

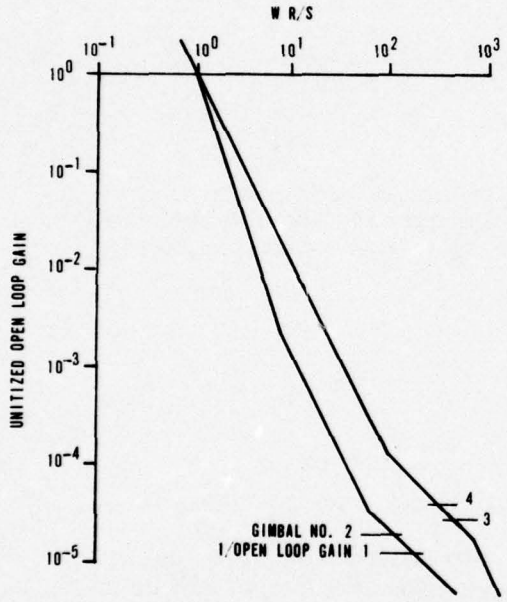


FIGURE 9.2-1. OPEN LOOP GAIN VERSUS FREQUENCY K_oG_o

0276-21

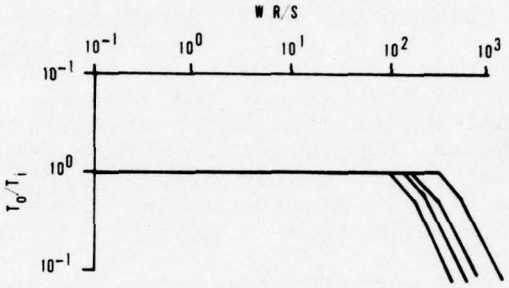


FIGURE 9.2-2. CLOSED LOOP GAIN VERSUS FREQUENCY K_cG_c

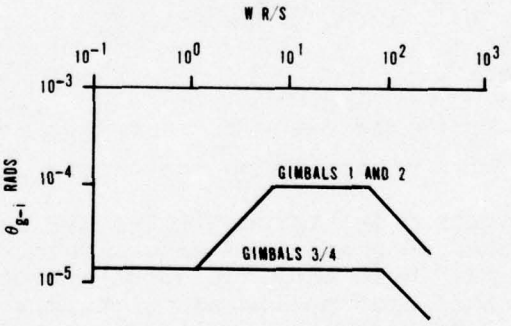


FIGURE 9.2-3. ERROR ANGLE VERSUS FREQUENCY

9.3 IMU MASS AND INERTIA DATA (Ref. TCL NO. 6)

Calculated values for the SPN/GEANS IMU mass and inertias are shown in Figure 9.3-1 and Table 9.3-1. Measured values are not available at this time.

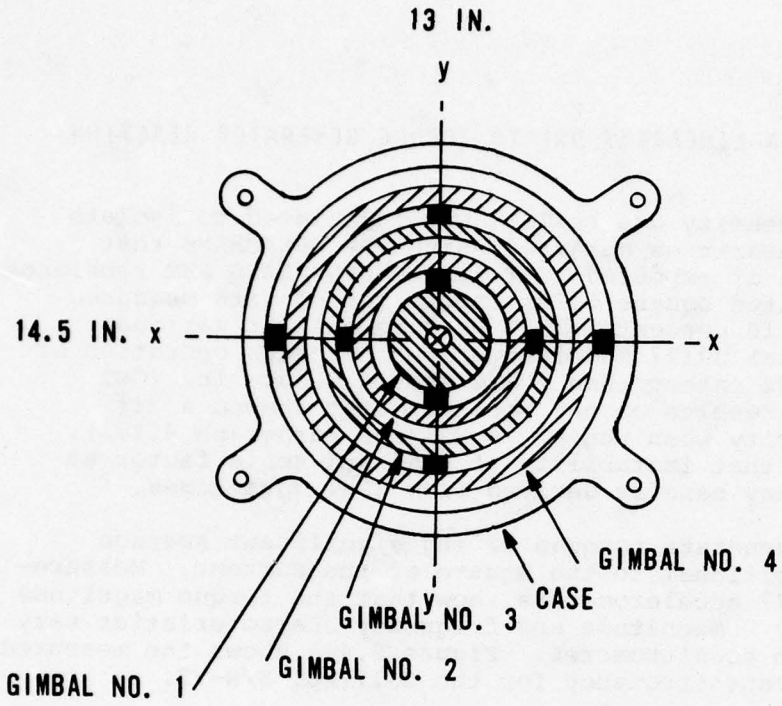


FIGURE 9.3-1. SPN/GEANS GIMBALS

TABLE 9.3-1. SPN/GEANS GYRO MASS AND INERTIA

Note: Normal gimbal operation maintains Gimbal 1 rotational axis perpendicular to the plane of Gimbal 3 - Gimbal 4 rotational axis.

	Inertia, in/oz/sec^2			Mass
	X-X	Y-Y	Z-Z	oz/in/sec^2
Gimbal 1	5.20	5.20	5.20	1.00
Gimbal 2	1.21	1.21	2.48	0.16
Gimbal 3	1.83	1.83	3.65	0.21
Gimbal 4	2.70	2.70	5.4	0.25
Case (Including External Electronics)	21.1	38.2	53.1	1.20

9.4 ACCELEROMETER NON-LINEARITY DUE TO TORQUE GENERATOR REACTION TORQUE (TGRT)

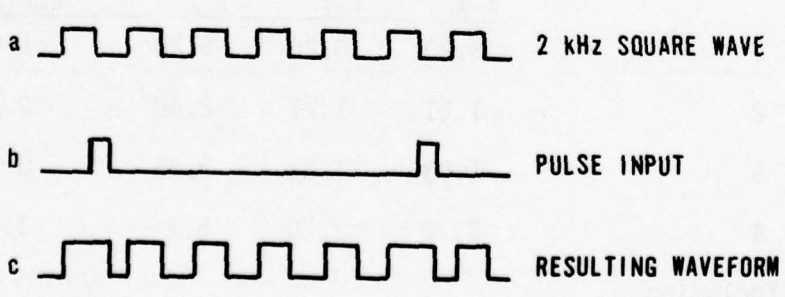
Accelerometer non-linearity due to TGRT was calculated to isolate the source of non-linearities measured using the SPN/GEANS test station. Calculation of expected TGRT in the SPN/GEANS PWM rebalance loops and with simulated square pulse inputs agreed with measured results within about 10 percent. TGRT measurements at various frequencies for several GG177 accelerometers indicates operation of the PWM loop at 16 kHz rather than 2 kHz should reduce the TGRT non-linearity. Test results on one accelerometer showed a 2:1 improvement in linearity when run at 16 Hz (See Paragraph 4.1.3). Later testing showed that instability of bias and scale factor at 16 kHz overshadowed any benefit derived from TGRT advantages.

Sinusoidal currents generate torques having significant average values that are proportional to the square of the current. Measurements made using GG177 accelerometers show that the torque magnitude varies with frequency. Magnitude and frequency characteristics vary from accelerometer to accelerometer. Figure 9.4-1 shows the measured TGRT scale factor versus frequency for the GG177P6, S/N-V8.

TGRT due to pulse inputs to the torquer was calculated by determining the square of the harmonic currents of the pulses, multiplying by the TGRT scale factor at each frequency, and adding the torques due to each harmonic frequency.

At 0 g input, the SPN/GEANS loop applies a 2 kHz, 80 ma peak to peak square wave of current to the torquer. As the g input is increased, 80 ma peak pulses, 1/8,000 second wide are periodically added to (or subtracted from) the square wave in such a manner as to shift the plus to minus switching time of a cycle forward (or backward) 1/8,000 of a second. This is depicted below:

0276-78



Just as the waveforms are added, the harmonics of the square and pulse waveforms can be algebraically added to determine the harmonic content of the resulting waveform.

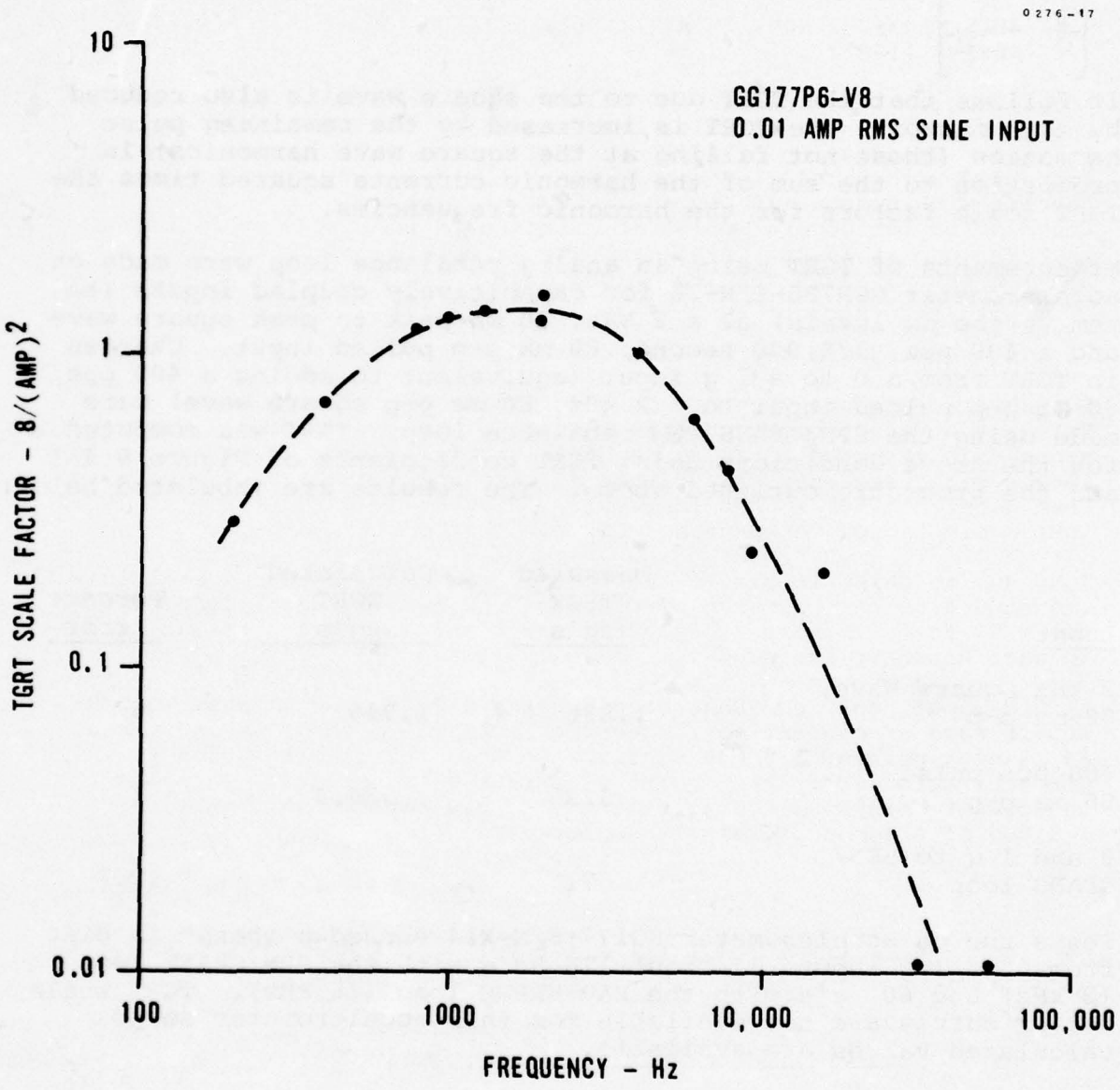


FIGURE 9.4-1. TGRT AS A FUNCTION OF FREQUENCY

If C is the ratio of the square wave frequency to the pulse repetition rate, then the square of each of the square wave harmonics is reduced in amplitude by

$$\left[\frac{1}{C} - \frac{1}{2C}^2\right].$$

It follows that the TGRT due to the square wave is also reduced by this factor. The TGRT is increased by the remaining pulse harmonics (those not falling at the square wave harmonics) in proportion to the sum of the harmonic currents squared times the TGRT scale factors for the harmonic frequencies.

Measurements of TGRT using an analog rebalance loop were made on accelerometer GGN7P6-S/N-V8 for capacitively coupled inputs (to remove the dc levels) of a 2 kHz, 80 ma peak to peak square wave and a 400 pps, 1/8,000 second, 80 ma p-p pulsed input. Changes in TGRT from a 0 to a 1 g input (equivalent to adding a 400 pps, 80 ma p-p pulsed input to a 2 kHz, 80 ma p-p square wave) were made using the SPN/GEANS PWM rebalance loop. TGRT was computed for the above conditions using TGRT coefficients of Figure 9.4-1 and the procedure outlined above. The results are tabulated below:

Input	Measured TRGT µg's	Calculated TGRT µg's	Percent Error
2 kHz Square Wave, 80 ma p-p	1,836	1,946	6
400 pps pulse 80 ma p-p	323	326.3	1
0 and 1 g to SPN/ GEANS loop	71	80	12.7

Tests run on accelerometer GG177-S/N-X14 showed a change in bias from 0 to 1 g inputs of about 110 µg's with the SPN/GEANS loop (2 kHz) and 60 µg's with the EAR HRPWM loop (16 kHz). TGRT scale factor curves are not available for this accelerometer so no calculated values are available.

The above results lead to the following conclusions:

1. TGRT due to square pulses can be calculated with less than 10 percent error using sinusoidal measurement of TGRT and the calculated harmonic amplitudes of the pulses.

2. The contribution of the SPN/GEANS test station to the measurement of accelerometer non-linearity was 12 percent for the accelerometer test.

3. Operation of the PWM loop at 16 kHz rather than 2 kHz will tend to reduce the accelerometer non-linearity due to TGRT, but bias and scale factor become more unstable. This is most likely due to the torquer bridge.

In the light of more recent tests, even though more is known about the effects of TGRT, it is recommended that the loop be run at 2 kHz.

Section 10

RELIABILITY PROGRAM

The Reliability effort was separated into two phases as follows:

1. Implementation of the requirements and groundrules established for the basic SPN/GEANS Reliability Program and,

2. Supplement these efforts through a cost effective informal reliability program necessary to support the EAR mod impact to the basic SPN/GEANS Program.

As such, a reliability design program which includes the following elements has been implemented:

1. Reliability Program Plan

2. Design Requirements Checklist

3. R-103 Reporting.

10.1 RELIABILITY PROGRAM PLAN

10.1.1 Reliability Education/Orientation

The following SPN/GEANS Reliability Program requirements and objectives were disseminated to EAR program personnel as required:

1. Design Procedures Manual

2. Division-Preferred Parts Manual

3. GEANS Derating Policy

4. SPN/GEANS Parts Control Plan

5. SPN/GEANS Program Directives.

10.1.2 Reliability Predictions

A preliminary prediction of the SPN/GEANS system plus EAR mod was completed and presented at the Preliminary Design Review. The purpose was to show the effect of the EAR mod on the overall SPN/GEANS MTBF. At that time, based on preliminary information for both the SPN/GEANS System and the EAR portion, the effect of the EAR mod on overall MTBF was less than 10 percent.

10.1.2.1 Failure Rates and Application Factors

The primary source of failure rate data is the "Failure Rate Sources and Environmental Factors Manual" approved by the Air Force for the SPN/GEANS Program.

10.1.3 Parts Selection and Standardization

Parts to be utilized in the EAR Mod Program have been selected to the maximum extent practical from the criteria established on the SPN/GEANS Program.

10.1.3.1 Program Parts Slection Listing (PPSL)

The Program Parts Selection Listing developed and maintained under the basic SPN/GEANS Contract No. F33615-73-C-1247 has been made available to EAR Program personnel.

10.1.3.2 Approved Supplier Listing

The Approved Supplier Listing developed and maintained under the basic SPN/GEANS Contract No. F33615-73-C-1247 has been made available to EAR Program personnel.

10.2 DESIGN REQUIREMENTS CHECK-LIST (DRCL)

The DRCL specifying all the technical elements of the design plus the design procedures imposed by the Design Procedures Manual and the unique customer technical requirements imposed by the EAR contract has been completed, approved by the program and is in effect.

10.3 REPORTING

A formal reliability program has not been implemented; however, the requirements of AFSCM 310-1C-R-103 excluding paragraphs 1c, e, f, g and i will be adhered to as required by Contract F-33615-74-C-1068, dated 18 March 1974.

Section 11

MAINTAINABILITY AND COST OF OWNERSHIP

11.1 MAINTAINABILITY

A maintainability analysis of the SPN/GEAN modifications for EAR motion compensation was performed on a continuous basis through part of the brassboard/breadboard design and test programs until terminated on 5 September 1975.

The analysis would be performed through liaison with Design Engineering, review of schematics and other engineering documentation for the various concepts under study. The analysis would include a study of the requirements for test, checkout, inspection, parts or components replacement, disassembly, assembly, diagnostics and fault isolation followed by provisions for access and other design features to facilitate performance of all maintenance tasks as they relate to EAR modifications.

Ease of maintenance and the mean-time-to-repair are determined to a large extent by packaging. Although the firm SPN/GEANS EAR modification packaging concept has not been established, the increased maintenance is not anticipated to be significant.

Data derived from the maintainability analysis will be used in projecting the cost of maintenance technical manuals, training, support equipment, spare parts, and development of the maintenance and support concepts. The detailed maintenance concept will evolve into a detailed maintenance plan for the modified SPN/GEANS performing motion compensation for EAR. Outputs from the analysis which will be included in the maintenance plan are:

1. Depth and frequency of maintenance required at each level.
2. Step by step maintenance tasks for inclusion in future technical manuals.
3. Facilities requirements as appropriate.
4. Support equipment and tools required.
5. Skill levels and quantities of maintenance personnel required.
6. Training requirements and recommendations.

11.2 COST OF OWNERSHIP

The cost of prime hardware and support resources resulting from SPN/GEANS EAR modifications, when identified by the maintainability analysis, will be incorporated into the Cost of Ownership Study.

The primary objective of the cost of ownership program is to minimize the impact on acquisition and total life cycle cost of the present SPN/GEANS as a result of incorporating the motion compensation modifications, and to provide a cost of ownership delta study from which valid cost projections for various modified SPN/GEANS quantities and support alternatives can be developed.

Calculations for the cost of ownership study will be performed using Honeywell's computerized life cycle cost model.

Section 12

SOFTWARE AND INTERFACE WITH EAR RDP

12.1 INTERFACE WITH EAR RDP

The major signal interfaces between the EAR RDP and the SPN/GEANS inertial navigation system (IMU and associated navigation computer) are outlined in Figure 12.1-1. As indicated therein, the existing interface between the IMU (via the IEU) and the navigation computer will be preserved essentially as is by adding a separate IMU/RDP interface unit to transmit the 256 Hz ΔV and resolver data, and by modifying the SPN/GEANS program software for interface compatibility with the RDP via the IAU and mock ACUC.

The RDP serial data I/O bus (Figure 12.1-1) utilizes a 2.5 MHz clock rate and word lengths of 20 bits consisting of 16 data bits plus parity and validity bits, with 4 clock dead times between successive words. The IAU and/or ACUC will do the necessary buffering to make the RDP and INS computer I/O word formats compatible, and the added IMU/RDP interface unit word format will be designed to be compatible with the RDP I/O data bus. The SPN computer serial I/O data bus utilizes a 1.0 MHz clock rate, and the serial data input and output word formats for the existing SPN/GEANS INS computer program are defined in Table 3.3.3.1-1 of Reference 1*. Each SPN computer output word is 32 bits long and consists of at least 16 data bits plus 8 bits for data identification and destination, so that a floating point (FL) output currently consists of two 32-bit output words with each word having 16 data bits. The current SPN/GEANS program provides 80 32-bit memory locations for placing outputs on the serial output data lines (SODL) and accepting inputs from the serial input data lines (SIDL). Approximately 173 additional 32-bit memory locations will have to be provided in SPN software for SODL and SIDL data words to and from the RDP, as indicated in Figure 12.1-1, plus flight test instrumentation words deemed necessary. (The present SPN program places all 15 32-bit SIDL words in both SIDL and SODL memory locations, the latter for possible instrumentation purposes.) These added SODL and SIDL words can be incorporated in the SPN computer program by providing the needed memory locations and by minor software changes to the SIDL and (possibly) SODL word formats. Possible tradeoffs, discussed subsequently, relate to reducing the number of SODL and SIDL words versus additional computations in the SPN computer program. Instrumentation requirements and tradeoffs, for SPN/GEANS INS diagnostic and calibration support software as well as for EAR system flight test demonstrations, must also be considered in terms of the number of added SPN memory locations.

---

* Reference 1. Computer Program Development Specification for the SPN/GEANS INS, 4th Prel Issue, Honeywell Aerospace Division, St. Petersburg, Florida, 9/1/74.

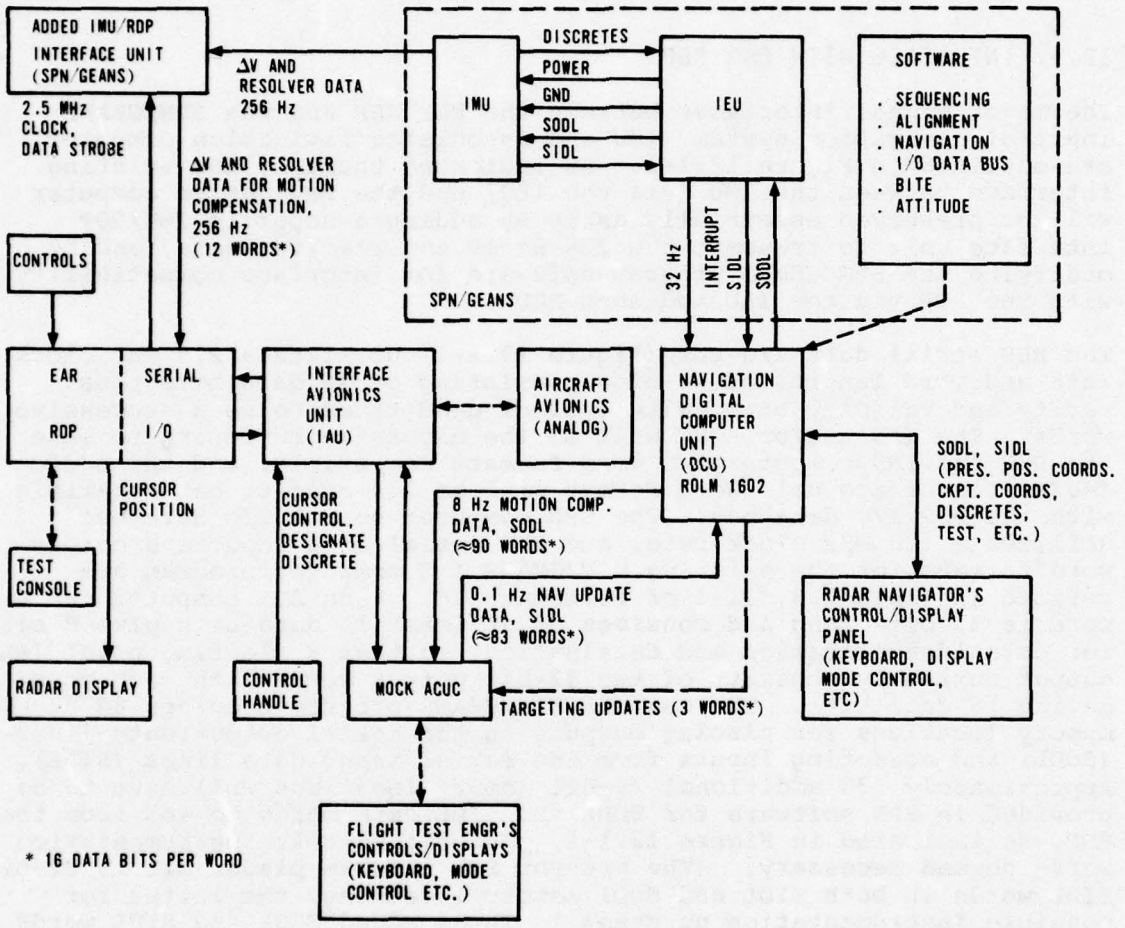


FIGURE 12.1-1. SIGNAL INTERFACES, EAR RDP AND SPN/GEANS INS, B-52 FLIGHT TEST

Motion Compensation Signal Interfaces

The specific RDP input signals from the IMU and the 1602 navigation computer used for motion compensation processing are defined in Table 12.1-1, together with update rate, word format, required versus available accuracy and available LSB. The Table 12.1-1 accuracy terms and notations are explained in accompanying notes. As indicated in Table 12.1-1, the specified (Reference 1) accuracies in the SPN/GEANS software program do not in some instances meet the required accuracies, so that SPN software modifications will be required. Such required modifications and tradeoffs will next be discussed relative to the Table 12.1-1 signal list.

12.2 SOFTWARE REQUIREMENTS

Table 12.1-1 defines the specific input words and associated accuracy requirements, assuming that motion compensation within the RDP will be done in local vertical coordinates.

The available accuracy of LGO, $t - t_o$, and checkpoint coordinates in Table 12.1-1, as defined in Reference 1, are inadequate, but correctable. Also, checkpoint height is not now stored or used in the SPN software program, although the latitudes and longitudes of 32 destinations and 8 targets are stored in memory locations. As indicated in Table 12.1-1 and Figure 12.1-1, an alternative is to store the checkpoint coordinates in the mock (or simulated) ACUC for the B-52 flight test program, but use of the INS navigation computer and associated control/display panel for this function appears preferable. The present SPN/GEANS control/display panel layout will be used to insert and display checkpoint coordinates with the required 10 foot accuracy (that is, to 0.001 arc-minutes of latitude and longitude instead of 0.1 arc-minutes). Therefore, software modifications including interface signal format changes between the C/D panel and INS computer will be required. However, no hardware changes to the INS C/D panel appear necessary for B-52 flight tests.

The inputs denoted by Note 5 in Table 12.1-1 are utilized in the RDP only at the beginning of each mapping frame time and their accuracy must be compatible with position fixtaking requirements. The difference between initial space stable aircraft coordinates (X, Y, Z) and space stable checkpoint coordinates (converted from checkpoint latitude, longitude and height in the RDP) will be transformed in the RDP via $[R_{2,0}]$ to compute the initial LOS vector (ΔE_0, ΔN_0, ΔD_0) in the local vertical frame. $[R_{2,0}]$ is now computed and used in SPN software and is available with adequate accuracy. It is noteworthy that if Table 12.1-1 checkpoint coordinates are stored in the ROLM 1602, the number of interface signals could be reduced significantly by ROLM computation of ΔE_0, ΔN_0, and ΔD_0. These three RDP input signals, in FL format, could then replace the first 17 FL signals in Table 12.1-1. However, possible interface and/or computation constraints in future operational mechanizations might weigh against this alternate approach, as also might the flight test mechanization technique

TABLE 12.1-1. RDP INPUTS FROM INS FOR MOTION COMPENSATION

Interface Signal Name and Def	From	Rate (Hz)	Format No. Words (16 Bits)	Req'd S.T. Accy (2)	Max Value	Avail LSB	Avail or Spec S.T. Accy	Req'd L.T. Accy	Avail L.T. Accy
A/C Pres Pos in SS Coords: X, Y, Z (5)	ROLM 1602	8	FL/6	10 ft (3)	21×10^6 ft	1.25 ft	6.6 ft (9)	1 nm	1 nm (10)
Ckpt (map center) Coords: Lat, Long, Ht above Sphere (11) (12) (5)	ROLM (12) or ACUC	8	FL/6	NA	πrad	0.2 μrad (4 ft equiv)	NA	10 ft eq	66 ft eq (9) (11)
Initiation Longitude: LGO (5)	1602	8	FL/2	NA	πrad	0.2 μrad (4 ft eq)	NA	10 ft eq	66 ft eq (9)
Mission time: $t-t_o$ (5)	1602	8	FL/2	0.005 sec	10^6 sec (9)	$10^6 \times 2^{-24}$ sec (0.06 sec)	2^{-5} sec = 0.03 sec (9)	0.005 sec	0.031 sec (9)
SS to LVDCM: $[R_{2,0}]$ (4) (5)	1602	8	FL/18	50×10^{-6}	1.0	1×10^{-6}	$<50 \times 10^{-6}$	50×10^{-6}	(10)
A/C Velocity in LC Coords: V_N, V_E, V_V (4) (13)	1602	8	FL/6	0.04 fps (6)	1600 fps	0.08 fps (6)	0.04 fps (6)	2 fps	<2 fps (10)
Incremental Velocities: V_x, V_y, V_z	IMU	256	FXBO/3	0.00125 fps	NA	0.00125 fps	0.00125 fps	NA	NA
Accel Axes (AA) to LV DCM: $[R_{2,15}]$ (4)	1602	8	FL/18	50×10^{-6}	16	1×10^{-6}	$\approx 50 \times 10^{-6}$	50×10^{-6}	(10)
Grav + Acc Bias, LV Coords: G_N, G_E, G_V (4)	1602	8	FL/6	50 μg	16g	1 μg	50 μg	50 μg	(10)
LV to A/C DCM: $[R_{5,2}]$	1602	8	FXBO/9	300×10^{-6}	1.0	$2^{-15} = 31 \times 10^{-6}$	$>500 \times 10^{-6}$ (8)	300×10^{-6}	$>500 \times 10^{-6}$ (8)
(3x1) Col DCMs: $[R_{5,7}]$, $[R_{5,9}]$, $[R_{5,10}]$	1602	8	FXBO/12	2×10^{-3}	1.0	$\times 10^{-6}$	$<2 \times 10^{-3}$	2×10^{-3}	$<2 \times 10^{-3}$
Uncorr Ref Res Angles: RES10, '20, '30, '40 (13)	1602	8	FXBO/4	215 μrad (7)	πrad	200 μrad	314 μrad (9)	NA	NA
Uncorr Current Res Angles: RES1, '2, '3, 4	IMU	256	FXBO/8	215 μrad (7)	πrad	200 μrad	314 μrad (9)	NA	NA
IMU Status	IMU	256	FXBO/1	NA	NA	NA	NA	NA	NA
Aircraft Roll Attitude (13) (14)	1602	8	FXBO/1	1 mrad	πrad	100 μrad	1 mrad	1 mrad	1 mrad

TABLE 12.1-1. RDP INPUTS FROM INS FOR MOTION COMPENSATION (Continued)

EXPLANATIONS OF NOTES 1 THROUGH 14

1 Long term accuracy is rms absolute (mean or bias) error over 4 seconds.

2 Short term accuracy is rms deviation (about mean) over 4 seconds.

3 Short term position error is rms deviation about trend (slope) over 2.5 minutes assuming an 800 foot peak Schuler oscillation.

4 These local vertical (LV) expressed coordinates would change to space stable (SS) coordinates if EAR motion compensation is done in SS coordinates, and $[R_{2,0}]$ would not be required.

5 These signals are used in RDP only at start of map frame time.

6 These accuracies are with use of current ΔVs into INS 1602 computer.

7 This short term accuracy is rms deviation over 1/8 second.

8 This is due primarily to 4th harmonic error of 360 μrad rms in each resolver.

9 These values are defined in SPN/GEANS software specification.

10 These available accuracies are navigation update dependent.

11 Checkpoint height is not stored in present SPN/GEANS program.

12 If "marked" target coordinates are stored in mock ACUC, three correction signals are needed from ROLM 1602 (Kalman filter to ACUC after targeting update.

13 These signals are available as SODL output words in present SPN/GEANS software program.

14 Used to correct EAR monopulse data for aircraft roll.

for navigation updating and for computing the initial LOS vector when mapping in the FDBS mode and attacking or designating a target of opportunity (for example, whose coordinates are not prestored but are computed or estimated from less accurate radar modes). Another flight test possibility is to prestore geocentric latitude, longitude and corrected radius or RAD (from Earth center to checkpoint) for each checkpoint in order to simplify the conversion of checkpoint coordinates to the space stable XYZ frame, against using LNO and $t-t_o$.

The Table 12.1-1 required short term accuracy in computing V_N, V_E and V_V is compatible with the existing quantization of the SPN IMU ΔV signals into the ROLM 1602; the ΔV LSB is 0.04 fps, but the effective ΔV transmitted is 0.08 fps. The resulting ROLM short term inaccuracy in computing V_N, V_E, and V_V can cause a frame to frame azimuth shift relative to the checkpoint for worst case parameter combinations. This will not affect update accuracy and the shift observed by the operator should not be bothersome if it is understood. In view of this, and since the maximum frame to frame shift should be only a few resolution cells, reducing the current 0.08 fps ΔV quantization (from the IMU to the ROLM 1602) is not recommended. These V_N, V_E, and V_V signals are used in the RDP at the start of each mapping frame time, and are very accurately updated at a 256 Hz rate via the ΔV_X, ΔV_Y, and ΔV_Z inputs to the RDP (Table 12.1-1) by transforming these 256 Hz ΔV inputs through $[R_{2,15}]$ and correcting for G_N, G_E, and G_V.

Computation in the ROLM 1602 of $[R_{2,15}]$, needed in the RDP to convert the 256 Hz ΔV_X, ΔV_Y, and ΔV_Z velocities to the LV frame and also in the 1602 to convert stored accelerometer biases to the LV frame for inclusion in the G_N, G_E, and G_V interface signals to the RDP, requires the matrix multiplication of $[R_{2,10}]$ and $[R_{10,15}]$ both of which exist in SPN software in floating point (FL) format. The added processing time to compute $[R_{2,15}]$ plus G_N, G_E, and G_V at 8 Hz is approximately 32 msec per second. The through-put rate is now about 625 msec per second for the Reference 1 SPN Program so that the added computation time is tolerable but not insignificant.

The required attitude DCMs in Table 12.1-1 are not now outputs from SPN software, but can be readily provided. $[R_{2,5}]$ is now computed as $[R_{2,10}] \times [R_{10,5}]$ with $[R_{10,5}]$ and $[R_{2,5}]$ in FXBO format, and the required elements of the (3x1) column vectors in Table 12.1-1 are now computed as row elements in the determination of $[R_{10,5}]$. Through-put rate is penalized but little by the added FXBO multiplications. $[R_{2,5}]$ is now updated as a 32 Hz rate based on resolver inputs to the ROLM 1602 at the start of each 1/32 second interval. These resolver inputs to the ROLM are the uncorrected RES10, RES20, and RES30 inputs needed in the RDP along with the associated $[R_{5,2}]$ DCM.

The major remaining accuracy problem associated with the Table 12.1-1 RDP input signals is the error in the 8 Hz computation of $[R_{5,2}]$. This error is due primarily to 4th harmonic resolver variations of about 360 μrads rms, and will cause both short term (deviation about the mean) and long term (bias) errors during any 4 second interval. The

total rms error for each resolver must be reduced to about 215 μrad to attain the required overall accuracy of 300 μrad in computing $[R_{5,2}]$, and further investigation of resolver accuracy improvements is needed. Resolver harmonic and bias accuracy errors on the 8 Hz and 256 Hz inputs to the RDP in Table 12.1-1 (see Note 7) are not critical because they tend to cancel out when computing RES1-RES10, etc., during each 1/8 second interval while updating $[R_{5,2}]$ at a 256 Hz rate in the RDP. The 256 Hz, 8 word resolver data into the RDP consists of successive resolver measurements sampled at a 512 Hz rate.

BITE/Diagnostic

The BITE/Diagnostic software changes will be concerned only with those areas affected by the motion compensation modification. These areas are in the IMU and are:

- VMU (for ΔV accuracy improvement)
- Logic Tray (for providing 256 Hz data to RDP)

The changes will provide capability consistent with the existing SPN/GEANS BITE and diagnostic software.

176-13551

Appendix

SOFTWARE LISTING

EAR DATA RECORD MODULE

```
                                * EARS DATA RECORD                                          10/20/75  PAGE    1
0001                            * EARS DATA RECORD                                          10/20/75              0001
0002                            * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   0002
0003                            *                                                                       *     0003
0004                            *                          NOTE !!!!!!!                                 *     0004
0005                            * IF USED WITH DELTA V PROGRAM , SET LOC '1071 TO 'NOP'                  *     0005
0006                            *                                                                       *     0006
0007                            * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   0007
0008                            *                                                                             0008
0009                            * THIS DATA BASE WAS UPDATED 02 APRIL 1974                                    0009
0010                            *                                                                             0010
0011                                 ORG   '0500            STANDARD CONSTANTS                               0011
0012                 000026     TMPR EQU   '26              TEMPORARY STORAGE                                0012
0013                 000040     DPTT EQU   '40              DBL PREC ARGUMENT FOR 'ATND'                     0013
0014                 000042     DPTD EQU   DPTT+2           DBL PREC ARGUMENT FOR 'DIVD'                     0014
0015                 000044     DPTM EQU   DPTD+2           DBL PREC ARGUMENT FOR 'MPYD'                     0015
0016                 000044     DPT0 EQU   DPTM             DBL PRECISION ARGUMENT                           0016
0017                 000046     TMPC EQU   DPTM+2           TEMPORARY STORAGE FOR SUBROUTINES                0017
0018 00500           000000     ZERO DBP   0BB30            DOUBLE PRECISION INTEGER  +0                     0018
     00501           000000
0019 00502           000000     BB1  DBP   1BB30            DOUBLE PRECISION INTEGER  +1                     0019
     00503           000001
0020                 000502     PBB1 EQU   BB1              ANOTHER NAME FOR +1BB30                          0020
0021 00504           020000     A45  DBP   +.25BB0          45 DEGREE CONSTANT  (PI-RADIANS)                 0021
     00505           000000
0022 00506           040000     A90  DBP   +.50BB0          90 DEGREE CONSTANT  (PI-RADIANS)                 0022
     00507           000000
0023 00510           077777     ONE  OCT   077777,077777   MAXIMUM + DBL PREC NUMBER (1-2**-30)             0023
     00511           077777
0024                 000511     CB1  EQU   *-1  ='077777   ONLY  BIT   1 OFF, ALL OTHERS  ON               0024
0025 00512           137777     CB2  OCT   137777          ONLY  BIT   2 OFF, ALL OTHERS  ON               0025
0026 00513           157777     CB3  OCT   157777          ONLY  BIT   3 OFF, ALL OTHERS  ON               0026
0027 00514           167777     CB4  OCT   167777          ONLY  BIT   4 OFF, ALL OTHERS  ON               0027
0028 00515           173777     CB5  OCT   173777          ONLY  BIT   5 OFF, ALL OTHERS  ON               0028
0029 00516           175777     CB6  OCT   175777          ONLY  BIT   6 OFF, ALL OTHERS  ON               0029
0030 00517           176777     CB7  OCT   176777          ONLY  BIT   7 OFF, ALL OTHERS  ON               0030
0031 00520           177377     CB8  OCT   177377          ONLY  BIT   8 OFF, ALL OTHERS  ON               0031
0032 00521           177577     CB9  OCT   177577          ONLY  BIT   9 OFF, ALL OTHERS  ON               0032
0033 00522           177677     CB10 OCT   177677          ONLY  BIT  10 OFF, ALL OTHERS  ON               0033
0034 00523           177737     CB11 OCT   177737          ONLY  BIT  11 OFF, ALL OTHERS  ON               0034
0035 00524           177757     CB12 OCT   177757          ONLY  BIT  12 OFF, ALL OTHERS  ON               0035
0036 00525           177767     CB13 OCT   177767          ONLY  BIT  13 OFF, ALL OTHERS  ON               0036
0037 00526           177773     CB14 OCT   177773          ONLY  BIT  14 OFF, ALL OTHERS  ON               0037
0038 00527           177775     CB15 OCT   177775          ONLY  BIT  15 OFF, ALL OTHERS  ON               0038
0039 00530           177776     CB16 OCT   177776          ONLY  BIT  16 OFF, ALL OTHERS  ON               0039
0040                            *                                                                             0040
0041 00531           100000     B1   OCT   100000          ONLY  BIT   1  ON, ALL OTHERS OFF               0041
0042 00532           040000     B2   OCT   040000          ONLY  BIT   2  ON, ALL OTHERS OFF               0042
0043 00533           020000     B3   OCT   020000          ONLY  BIT   3  ON, ALL OTHERS OFF               0043
0044 00534           010000     B4   OCT   010000          ONLY  BIT   4  ON, ALL OTHERS OFF               0044
0045 00535           004000     B5   OCT   004000          ONLY  BIT   5  ON, ALL OTHERS OFF               0045
0046 00536           002000     B6   OCT   002000          ONLY  BIT   6  ON, ALL OTHERS OFF               0046
0047 00537           001000     B7   OCT   001000          ONLY  BIT   7  ON, ALL OTHERS OFF               0047
0048 00540           000400     B8   OCT   000400          ONLY  BIT   8  ON, ALL OTHERS OFF               0048
0049 00541           000200     B9   OCT   000200          ONLY  BIT   9  ON, ALL OTHERS OFF               0049
0050 00542           000100     B10  OCT   000100          ONLY  BIT  10  ON, ALL OTHERS OFF               0050
```

```
                        * EARS DATA RECORD                                                  10/20/75  PAGE    2
0051 00543   000040     B11  OCT   000040          ONLY  BIT  11  ON, ALL OTHERS OFF                    0051
0052 00544   000020     B12  OCT   000020          ONLY  BIT  12  ON, ALL OTHERS OFF                    0052
0053 00545   000010     B13  OCT   000010          ONLY  BIT  13  ON, ALL OTHERS OFF                    0053
0054 00546   000004     B14  OCT   000004          ONLY  BIT  14  ON, ALL OTHERS OFF                    0054
0055 00547   000002     B15  OCT   000002          ONLY  BIT  15  ON, ALL OTHERS OFF                    0055
0056 00550   000001     B16  OCT   000001          ONLY  BIT  16  ON, ALL OTHERS OFF                    0056
0057                    *                                                                            0057
0058         000531     N1   EQU   B1   ='100000  FIRST  1 BITS  ON, ALL OTHERS OFF                    0058
0059 00551   140000     N2   OCT   140000          FIRST  2 BITS  ON, ALL OTHERS OFF                    0059
0060 00552   160000     N3   OCT   160000          FIRST  3 BITS  ON, ALL OTHERS OFF                    0060
0061 00553   170000     N4   OCT   170000          FIRST  4 BITS  ON, ALL OTHERS OFF                    0061
0062 00554   174000     N5   OCT   174000          FIRST  5 BITS  ON, ALL OTHERS OFF                    0062
0063 00555   176000     N6   OCT   176000          FIRST  6 BITS  ON, ALL OTHERS OFF                    0063
0064 00556   177000     N7   OCT   177000          FIRST  7 BITS  ON, ALL OTHERS OFF                    0064
0065 00557   177400     N8   OCT   177400          FIRST  8 BITS  ON, ALL OTHERS OFF                    0065
0066 00560   177600     N9   OCT   177600          FIRST  9 BITS  ON, ALL OTHERS OFF                    0066
0067 00561   177700     N10  OCT   177700          FIRST 10 BITS  ON, ALL OTHERS OFF                    0067
0068 00562   177740     N11  OCT   177740          FIRST 11 BITS  ON, ALL OTHERS OFF                    0068
0069 00563   177760     N12  OCT   177760          FIRST 12 BITS  ON, ALL OTHERS OFF                    0069
0070 00564   177770     N13  OCT   177770          FIRST 13 BITS  ON, ALL OTHERS OFF                    0070
0071 00565   177774     N14  OCT   177774          FIRST 14 BITS  ON, ALL OTHERS OFF                    0071
0072         000530     N15  EQU   CB16 ='177776  FIRST 15 BITS  ON, ALL OTHERS OFF                    0072
0073                    *                                                                            0073
0074 00566   177777     MBB1 DBP   -1BB30          MAXIMUM + DBL PREC NUMBER (-2**-30)                  0074
     00567   077777
0075         000566     N16  EQU   *-2  ='177777  FIRST 16 BITS  ON, ALL OTHERS OFF                    0075
0076                    *                                                                            0076
0077         000567     CN1  EQU   *-1  ='077777  FIRST  1 BITS OFF, ALL OTHERS  ON                    0077
0078 00570   037777     CN2  OCT   037777          FIRST  2 BITS OFF, ALL OTHERS  ON                    0078
0079 00571   017777     CN3  OCT   017777          FIRST  3 BITS OFF, ALL OTHERS  ON                    0079
0080 00572   007777     CN4  OCT   007777          FIRST  4 BITS OFF, ALL OTHERS  ON                    0080
0081 00573   003777     CN5  OCT   003777          FIRST  5 BITS OFF, ALL OTHERS  ON                    0081
0082 00574   001777     CN6  OCT   001777          FIRST  6 BITS OFF, ALL OTHERS  ON                    0082
0083 00575   000777     CN7  OCT   000777          FIRST  7 BITS OFF, ALL OTHERS  ON                    0083
0084 00576   000377     CN8  OCT   000377          FIRST  8 BITS OFF, ALL OTHERS  ON                    0084
0085 00577   000177     CN9  OCT   000177          FIRST  9 BITS OFF, ALL OTHERS  ON                    0085
0086 00600   000077     CN10 OCT   000077          FIRST 10 BITS OFF, ALL OTHERS  ON                    0086
0087 00601   000037     CN11 OCT   000037          FIRST 11 BITS OFF, ALL OTHERS  ON                    0087
0088 00602   000017     CN12 OCT   000017          FIRST 12 BITS OFF, ALL OTHERS  ON                    0088
0089 00603   000007     CN13 OCT   000007          FIRST 13 BITS OFF, ALL OTHERS  ON                    0089
0090 00604   000003     CN14 OCT   000003          FIRST 14 BITS OFF, ALL OTHERS  ON                    0090
0091         000550     CN15 EQU   B16  ='000001  FIRST 15 BITS OFF, ALL OTHERS  ON                    0091
0092         000500     CN16 EQU   ZERO ='000000  FIRST 16 BITS OFF, ALL OTHERS  ON                    0092
0093                    *                                                                            0093
0094         000517     M513 EQU   CB7             DECIMAL INTEGER  -513                              0094
0095         000556     M512 EQU   N7              DECIMAL INTEGER  -512                              0095
0096         000520     M257 EQU   CB8             DECIMAL INTEGER  -257                              0096
0097         000557     M256 EQU   N8              DECIMAL INTEGER  -256                              0097
0098         000521     M129 EQU   CB9             DECIMAL INTEGER  -129                              0098
0099         000560     M128 EQU   N9              DECIMAL INTEGER  -128                              0099
0100         000522     M65  EQU   CB10            DECIMAL INTEGER  -65                               0100
0101         000561     M64  EQU   N10             DECIMAL INTEGER  -64                               0101
0102         000523     M33  EQU   CB11 =-33       DECIMAL INTEGER  -33                               0102
0103         000562     M32  EQU   N11  =-32       DECIMAL INTEGER  -32                               0103
0104 00605   177756     M18  DEC   -18B15           DECIMAL INTEGER  -18                               0104
```

```
                        * EARS DATA RECORD                                                  10/20/75  PAGE    3
0105            000524  M17  EQU   CB12 =-17       DECIMAL INTEGER  -17                                  0105
0106            000563  M16  EQU   N12  =-16       DECIMAL INTEGER  -16                                  0106
0107 00606      177764  M12  DEC   -12B15          DECIMAL INTEGER  -12                                  0107
0108 00607      177765  M11  DEC   -11B15          DECIMAL INTEGER  -11                                  0108
0109 00610      177766  M10  DEC   -10B15          DECIMAL INTEGER  -10                                  0109
0110            000525  M9   EQU   CB13 =-9        DECIMAL INTEGER  - 9                                  0110
0111            000564  M8   EQU   N13  =-8        DECIMAL INTEGER  - 8                                  0111
0112 00611      177771  M7   DEC   -7B15          DECIMAL INTEGER  - 7                                  0112
0113 00612      177772  M6   DEC   -6B15          DECIMAL INTEGER  - 6                                  0113
0114            000526  M5   EQU   CB14 =-5       DECIMAL INTEGER  - 5                                  0114
0115            000565  M4   EQU   N14  =-4        DECIMAL INTEGER  - 4                                  0115
0116            000527  M3   EQU   CB15 =-3       DECIMAL INTEGER  - 3                                  0116
0117            000530  M2   EQU   CB16 =-2       DECIMAL INTEGER  - 2                                  0117
0118            000566  M1   EQU   N16  =-1        DECIMAL INTEGER  - 1                                  0118
0119            000500  P0   EQU   CN16 =+0       DECIMAL INTEGER  + 0                                  0119
0120            000550  P1   EQU   B16  =+1        DECIMAL INTEGER  + 1                                  0120
0121            000547  P2   EQU   B15  =+2        DECIMAL INTEGER  + 2                                  0121
0122            000604  P3   EQU   CN14 =+3        DECIMAL INTEGER  + 3                                  0122
0123            000546  P4   EQU   B14  =+4        DECIMAL INTEGER  + 4                                  0123
0124 00613      000005  P5   DEC   +5B15          DECIMAL INTEGER  + 5                                  0124
0125 00614      000006  P6   DEC   +6B15          DECIMAL INTEGER  + 6                                  0125
0126            000603  P7   EQU   CN13 =+7       DECIMAL INTEGER  + 7                                  0126
0127            000545  P8   EQU   B13  =+8        DECIMAL INTEGER  + 8                                  0127
0128 00615      000011  P9   DEC   +9B15          DECIMAL INTEGER  + 9                                  0128
0129 00616      000012  P10  DEC   +10B15         DECIMAL INTEGER  +10                                  3129
0130 00617      000013  P11  DEC   +11B15         DECIMAL INTEGER  +11                                  0130
0131 00620      000014  P12  DEC   +12B15         DECIMAL INTEGER  +12                                  0131
0132            000602  P15  EQU   CN12 =+15      DECIMAL INTEGER  +15                                  0132
0133            000544  P16  EQU   B12  =+16      DECIMAL INTEGER  +16                                  0133
0134 00621      000022  P18  DEC   +18B15         DECIMAL INTEGER  +31                                  0134
0135 00622      000030  P24  DEC   +24B15         DECIMAL INTEGER  +24                                  0135
0136            000601  P31  EQU   CN11 =+31      DECIMAL INTEGER  +31                                  0136
0137            000543  P32  EQU   B11  =+32      DECIMAL INTEGER  +32                                  0137
0138            000600  P63  EQU   CN10           DECIMAL INTEGER  +63                                  0138
0139            000542  P64  EQU   B10            DECIMAL INTEGER  +64                                  0139
0140            000577  P127 EQU   CN9            DECIMAL INTEGER  +127                                 0140
0141            000541  P128 EQU   B9             DECIMAL INTEGER  +128                                 0141
0142            000576  P255 EQU   CN8            DECIMAL INTEGER  +255                                 0142
0143            000540  P256 EQU   B8             DECIMAL INTEGER  +256                                 0143
0144            000575  P511 EQU   CN7            DECIMAL INTEGER  +511                                 0144
0145            000537  P512 EQU   B7             DECIMAL INTEGER  +512                                 0145
0146                    *                                                                               0146
0147 00624      000000  TIME DBP   0BB0                                                                 0147
     00625      000000
0148            000553  F000 EQU   N4   =$F000    1ST 4 BITS ON  MASK                                   0148
0149 00626      007400  0F00 HEX   0F00           2ND 4 BITS ON  MASK                                   0149
0150 00627      000360  00F0 HEX   00F0           3RD 4 BITS ON  MASK                                   0150
0151            000602  000F EQU   CN12 =$000F    4TH 4 BITS ON  MASK                                   0151
0152            000566  FFFF EQU   N16  =$FFFF    ALL 4 BITS ON  MASK                                   0152
0153            000572  0FFF EQU   CN4  =$0FFF    1ST 4 BITS OFF MASK                                   0153
0154 00630      170377  F0FF HEX   F0FF           2ND 4 BITS OFF MASK                                   0154
0155 00631      177417  FF0F HEX   FF0F           3RD 4 BITS OFF MASK                                   0155
0156            000563  FFF0 EQU   N12  =$FFF0    4TH 4 BITS OFF MASK                                   0156
0157            000576  00FF EQU   CN8  =$00FF    1ST, 2ND 4 BITS OFF MASK                              0157
0158            000557  FF00 EQU   N8   =$FF00    3RD, 4TH 4 BITS OFF MASK                              0158
```

```
                        * EARS DATA RECORD
0159                    *
0160 00632   0 000635   LDUM DAC   DUMY          LOCATION OF DUMY SUBROUTINE
0161 00633   177776     RNGE DFC   -2B15
0162 00634   0 017200   LSDB DAC    17200        ADR OF 1ST SODL WORD
0163                         EJCT
```

```
                                    * EARS DATA RECORD                                  10/20/75  PAGE    5
0164                                        ENT    AC1                                                  0164
0165                                        ENT    AC2                                                  0165
0166                                        ENT    AC3                                                  0166
0167                                        SUBR   DUMY                                                 0167
0168 00635    0 000000          DUMY        DAC    **                                                   0168
0169 00636   -0 01 00635                    JMP*   DUMY                                                 0169
0170 00637    000000            AC1         BSZ    1                                                    0170
0171 00640    000000            AC2         BSZ    1                                                    0171
0172 00641    000000            AC3         BSZ    1                                                    0172
0173                                        EJCT                                                        0173
```

```
                          * EARS DATA RECORD                                  10/20/75  PAGE    6
0174                              ORG   ´64
0175 00064   0 001171      32HZ   DAC   32HZ
0176                              ORG   ´70
0177 00070   0 001204      PI10   DAC   DMA
0178                              ORG   ´100
0179         000100        ES00   EQU   *
0180                          *
0181                              ORG   ´1000
0182                              SETB  ES02
0183 01000   140407              TCA                 NUMBER OF RECORDS MAKE THEM -
0184 01001   0 04 01167           STA   CTR           PUT IN COUNTER
0185 01002   0 02 01403           LDA   ABUF          ADR OF FORTRAN BUFFER
0186 01003   0 04 01404           STA   BPT           INIT BUFFER
0187 01004   140040              CRA                 NEED A ZERO
0188 01005  -0 04 01403           STA*  ABUF
0189 01006   0 04 00624           STA   TIME          CLEAR TIME
0190 01007   0 04 00625           STA   TIME+1
0191 01010   0 04 01160           STA   XI
0192 01011   0 04 01161           STA   XI+1
0193 01012   0 04 01162           STA   XI2
0194 01013   0 04 01163           STA   XI2+1
0195 01014   0 04 01331           STA   ACT
0196 01015   0 02 00566           LDA   M1
0197 01016   0 04 01330           STA   WF
0198 01017   0 04 01170           STA   FLAG          INIT FLAG
0199 01020   0 04 01342           STA   TM00          STATUS MARKER
0200 01021   0 04 01333           STA   TM01          DRIVE 0 OPERATIONAL MARKER
0201 01022   0 04 01335           STA   TM02          DRIVE 0 CYCLE DOWN MARKER
0202 01023   0 04 01337           STA   TM03          DRIVE 0 REWIND MARKER
0203 01024   0 04 01334           STA   TM11          DRIVE 1 OPERATIONAL MARKER
0204 01025   0 04 01336           STA   TM12          DRIVE 1 CYCLE DOWN MARKER
0205 01026   0 04 01340           STA   TM13          DRIVE 1 REWIND MARKER
0206 01027   0 04 01341           STA   TMX4          EOF FLAG (AT END OF TAPE)
0207 01030   0 02 01056           LDA   BUFA          BEGINNING ADDRESS OF BUFFER 1
0208 01031   0 04 01324           STA   DMC1          NECESSARY FOR RESTART
0209 01032   0 04 00020           STA   ´20           SET UP DMC CHANNEL 1 FOR BUF1
0210 01033   0 04 01377           STA   BEG1          USED IN FULL SUBROUTINE
0211 01034   0 06 00546           ADD   P4            MOVE TO START OF BLOCK
0212 01035   0 04 01376           STA   DRAD           STORE POINTER
0213 01036   0 02 01060           LDA   ENDA          END OF BUF1
0214 01037   0 04 01375           STA   DREA          ENDING ADDRESS OF BUFFER 1
0215 01040   0 04 00021           STA   ´021          ENDING ADDRESS FOR DMC
0216 01041   0 04 01401           STA   ENB1          ENDING ADDRESS FOR USE IN FULL SUBROUTINE
0217 01042   0 04 01326           STA   DME1          ENDING ADDRESS FOR USE IN DMC SUBROUTINE
0218 01043   0 02 01057           LDA   BUFB          BEG. OF BUFFER 2
0219 01044   0 04 01325           STA   DMC2          NECESSARY FOR RESTART
0220 01045   0 04 01400           STA   BEG2          NECESSARY FOR RESTART
0221 01046   0 02 01061           LDA   ENDB          ENDING ADDRESS OF BUFFER2
0222 01047   0 04 01327           STA   DME2          NECESSARY FOR RESTART
0223 01050   0 04 01402           STA   ENB2          NECESSARY FOR RESTART
0224 01051   0 02 01055           LDA   PRIM          INTERRUPT MASK
0225 01052   74 0120              SMK   ´0120        SET MASK
0226 01053   000401               ENB                 TURN EM ON
0227 01054   0 01 01054           JMP   *              WAIT FOR FIRST INTERRUP
0228                              EJCT
```

```
0229                    *                                                       0229
0230 01055   104000     PRIM OCT   104000      INTERRUPT MASK                   0230
0231 01056   0 001436   BUFA DAC   BUF1                                        0231
0232 01057   0 003442   BUFB DAC   BUF2                                        0232
0233 01060   0 003441   ENDA DAC   END1                                        0233
0234 01061   0 005445   ENDB DAC   END2                                        0234
0235 01062   000001     ECNT OCT   1           ERROR COUNTER, INITIALIZE TO +1  0235
0236                         EJCT                                             0236
```

```
0237                    *                                                                0237
0238 01063   000007    RC1  DBL                 GO TO DOUBLE MODD                       0238
0239 01064   0 02 00624      DLD   TIME          LOAD TIME                               0239
0240 01065   0 06 00502      DAD   BB1           ADD ONE                                 0240
0241 01066   0 04 00624      DST   TIME          PUT BACK                                0241
0242 01067   000005         SGL                 GO BACK                                 0242
0243 01070   0 02 17603      LDA   '17603        GET THE NEW DATA                        0243
0244                    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * 0244
0245                    * IFUSED WITH THE DELTA V PROGRAM SET THE NEXT LOC TO A 'NOP'  * 0245
0246                    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * 0246
0247 01071   0414 77        LGL   1             RESCALE                                 0247
0248 01072  -0 04 01376     STA*  DRAD                                                  0248
0249 01073   0 12 01376      IRS   DRAD          INC POINTER                             0249
0250 01074  '0 12 01170      IRS   FLAG          TEST FLAG                               0250
0251 01075   0 01 01102      JMP   *+5                                                   0251
0252 01076   0 04 01164      STA   MAX           INIT MAX                                0252
0253 01077   0 04 01165      STA   MIN           INIT MIN                                0253
0254 01100   0 04 01166      STA   ANG.          SAVE FIRST ANGLE                        0254
0255 01101   0 01 01112      JMP   *+9           CONTINUE                                0255
0256 01102   0 11 01164      CAS   MAX                                                   0256
0257 01103   0 04 01164      STA   MAX            YES ITS BIGGER                         0257
0258 01104   101000         NOP                                                         0258
0259 01105   101000         NOP                                                         0259
0260 01106   0 11 01165      CAS   MIN                                                   0260
0261 01107   0 01 01112      JMP   *+3                                                   0261
0262 01110   0 01 01112      JMP   *+2                                                   0262
0263 01111   0 04 01165      STA   MIN           YES ITS SMALLER                         0263
0264 01112   0 07 01166      SUB   ANG.          MALE DELTA                              0264
0265 01113   000007         DBL                                                         0265
0266 01114   0 04 00026      DST   TMPR          SAVE                                    0266
0267 01115   0 16 00026      MPY   TMPR          XI**2                                   0267
0268 01116   0 06 01162      DAD   XI2           XI2=XI2++SUM                            0268
0269 01117   0 04 01162      DST   XI2           SAVE                                    0269
0270 01120   0 13 00026      IMA   TMPR          GET IT BACK                             0270
0271 01121   0 16 00550      MPY   B16           RESCALE                                 0271
0272 01122   0 06 01160      DAD   XI            XI=XI+SUM                               0272
0273 01123   0 04 01160      DST   XI                                                    0273
0274 01124   000005         SGL                                                         0274
0275 01125   0 02 01375      LDA   DREA            END OF BUFFER                       0275
0276 01126   0 11 01376      CAS   DRAD                                                  0276
0277 01127   0 01 01132      JMP   WAIT          NOT FULL YET                            0277
0278 01130   0 01 01132      JMP   WAIT          NOT FULL YET                            0278
0279 01131   0 10 01343      JST   FULL          EX. BUF AND START WRITE                 0279
0280 01132   34 0110    WAIT SKS   '110         BUSY?                                   0280
0281 01133   0 01 01142      JMP   WAT1          YES GO WAIT                             0281
0282 01134   0 02 01330      LDA   WF            LOAD FLAG                               0282
0283 01135   100400         SPL                 WAS IT PLUS                             0283
0284 01136   0 01 01142      JMP   WAT1          NO, ALL OK, GO WAIT                     0284
0285 01137   101040         SNZ                 WAS IT ZERO                             0285
0286 01140   0 01 01147      JMP   WAT2          YES GO PROCESS                          0286
0287 01141   0 10 01207      JST   WRIT          WAS A 1 GO START NEW WRITE              0287
0288 01142   0 02 01165 WAT1 LDA   MIN           LOAD MIN                                0288
0289 01143   000201         IAB                 PUT IN B                                0289
0290 01144   0 02 01164      LDA   MAX           LOAD MAX                                0290
0291 01145   000401         ENB                 TURN ON INTERRUPTS                      0291
```

```
0292 01146   0 01 01142      JMP   WAT1     WAIT                          0292
0293 01147   34 0210     WAT2 SKS   '210     ANY ERRORS                    0293
0294 01150   0 01 01154       JMP   WAT3     YES GO PROCESS                0294
0295 01151   0 02 00566       LDA   M1       NO, RESET FLAG                0295
0296 01152   0 04 01330 WAT4  STA   WF       STORE FLAG                    0296
0297 01153   0 01 01142       JMP   WAT1     GO WAIT                       0297
0298 01154   14 1510    WAT3  OCP   '1510    BACK                          0298
0299 01155   0 02 00550       LDA   P1       NEED A 1 FOR FLAG             0299
0300 01156   0 01 01152       JMP   WAT4     GO SET AND THEN WAIT          0300
0301 01160   000000      XI    DBP   0                                     0301
     01161   000000
0302 01162   000000      XI2   DBP   0                                     0302
     01163   000000
0303 01164   000000      MAX   DEC   0                                     0303
0304 01165   000000      MIN   DEC   0                                     0304
0305 01166   000000      ANG.  DEC   0                                     0305
0306 01167   000000      CTR   DEC   0                                     0306
0307 01170   000000      FLAG  DEC   0                                     0307
0308                           EJCT                                       0308
```

```
0309                    ********************************************************************************  0309
0310                    *                                                                                 0310
0311                    * 32 HERTZ INTERRUPT SERVICE ROUTINE:                                             0311
0312                    *   THIS ROUTINE STARTS THE SERIAL DATA BUS, CALLS TORQUING, THEN                  0312
0313                    *   RETURNS TO CALLING PROGRAM                                                    0313
0314                    *                                                                                 0314
0315 01171  0 000000    32HZ DAC   **                                                                     0315
0316 01172  000011           DXA                    SETUP TO LEAVE EXTENDED ADDRESSING MODE               0316
0317 01173  0 01 01174       JMP   **+1             LEAVE          EXTENDED ADDRESSING MODE               0317
0318 01174  14 0124          OCP   '0124            STOP SDB IF BUSY (IT SHOULDN'T BE)                    0318
0319 01175  0 02 00634       LDA   LSDB             LOAD LOCATION OF SODL                                 0319
0320 01176  74 0124          SMK   '0124            LOAD DMA WITH ADDRESS                                 0320
0321 01177  0 02 00633       LDA   RNGE             LOAD -(NUMBER OF SODL WORDS)                          0321
0322 01200  74 1124          SMK   '1124            LOAD DMA WITH RANGE                                   0322
0323 01201  14 1020     NOGO OCP   '1020            RESET NO-GO TIMER                                     0323
0324 01202  14 0024          OCP   '0024            START DMA FOR SDB TRANSFER                            0324
0325 01203  0 01 01132       JMP   WAIT                                                                   0325
0326                    *                                                                                 0326
0327                    * SERIAL DATA BUS COMPLETE:                                                       0327
0328                    *   THIS ROUTINE CHECKS FOR RESTART OF REAL-TIME ROUTINES UPON SDB                 0328
0329                    *   TRANSFER COMPLETE                                                             0329
0330                    *                                                                                 0330
0331 01204  0 000000    DMA  DAC   **                                                                     0331
0332 01205  000011           DXA                    SETUP TO LEAVE EXTENDED ADDRESSING MODE               0332
0333 01206  0 01 01063       JMP   RC1               GO START RECORD                                       0333
0334        001207      ES01 EQU   *                                                                     0334
0335                         EJCT                                                                      0335
```

```
0336                    *     MAG TAPE WRITE ROUTINE, WRITES BINARY(3CH/WORD) ON ACTIVE DRIVE
0337                    *
0338 01207   0 000000   WRIT DAC   **
0339 01210   0 02 01400       LDA   BEG2          START OF BUFFER
0340 01211   0 04 00026       STA   TMPR          STORE FOR INDERECTING
0341 01212   0 02 00624       LDA   TIME          FIRST PART
0342 01213  -0 04 00026       STA*  TMPR
0343 01214   0 12 00026       IRS   TMPR
0344 01215   0 02 00625       LDA   TIME+1        LOAD TIME
0345 01216  -0 04 00026       STA*  TMPR
0346 01217   0 12 00026       IRS   TMPR          ; MOVE TO NEXT LOC
0347 01220   0 02 01164       LDA   MAX           ; MAX PUL THIS RECORD
0348 01221  -0 04 00026       STA*  TMPR          ; STORE
0349 01222   0 12 00026       IRS   TMPR
0350 01223   0 02 01165       LDA   MIN           MIN PUL THIS RECORD
0351 01224  -0 04 00026       STA*  TMPR
0352 01225   0 02 00566       LDA   M1
0353 01226   0 04 01170       STA   FLAG          INIT FOR FIRST PASS THIS RECD
0354 01227  -0 12 01403       IRS*  ABUF          INC RECORD COUNTER
0355 01230   0 35 00611       LDX   M7            ; FOR INDEXING
0356 01231   1 02 01167       LDA   XI+7,1        LOAD DATA
0357 01232   0 12 01404       IRS   BPT           INC POINTER
0358 01233  -0 04 01404       STA*  BPT           PUT IN BUFFER
0359 01234   140040          CRA                 NEED A ZERO
0360 01235   1 04 01167       STA   XI+7,1        RESET TO ZERO
0361 01236   0 12 00000       IRS   0             INC COUNTER
0362 01237   0 01 01231       JMP   *-6           LOOP TILL COMPLETE
0363 01240   0 02 01342       LDA   TM00          CHECK STATUS MARKER
0364 01241   101400          SMI                 NEGATIVE IS GOOD
0365 01242   0 01 01306       JMP   WRT5          NOT READY EXIT
0366 01243   14 0310    WRT1 OCP   '0310         SET UP NORMAL DMC, REALLY SET UP TCU
0367 01244   34 1110          SKS   '1110         SKIP IF OPERATIONAL
0368 01245   0 01 01305       JMP   WRT4          PROBLEM, SET MARKERS +
0369 01246   34 0710          SKS   '0710         IS DRIVE IN PERMIT
0370 01247   0 01 01305       JMP   WRT4          NO, SET MARKERS +
0371 01250   14 0310    WRT2 OCP   '0310         OK, NOW SET UP DMC
0372 01251   14 1010    WRT3 OCP   '1010         WRITE BINARY (3CH/WORD)
0373 01252   140040          CRA                 NEED A ZERO
0374 01253   0 04 01330       STA   WF            SET WRITE MARKER FOR WRITE IN PROCESS
0375 01254   100020    WRT6 SR1                  TEST 1
0376 01255   0 01 01260       JMP   WRT7          GO STOP
0377 01256   0 12 01167       IRS   CTR           ARE WE DONE
0378 01257  -0 01 01207       JMP*  WRIT          RETURN
0379 01260   001001    WRT7 INH                  DONT WANT EM ANY MORE
0380 01261   34 0110          SKS   '110          ARE WE BUSY
0381 01262   0 01 01261       JMP   *-1
0382 01263   34 1110          SKS   '1110         OPERATIONAL
0383 01264   0 01 01266       JMP   *+2           NO, SKIP
0384 01265   14 0610          OCP   '610          WRITE FILE MARK
0385 01266   0 10 00000       CALL  FORT          DO THE FORTRAN PROC
0386 01267   0 005446        DAC   BUF3          FORTRAN BUFFER
0387 01270   000000          HLT                 WAIT
0388 01271   101000          NOP                 START PATCH IF NEEDED
0389 01272   101000          NOP
0390 01273   101000          NOP
```

```
                        * EARS DATA RECORD
0391 01274   101000             NOP
0392 01275   101000             NOP
0393 01276   101000             NOP
0394 01277   101000             NOP
0395 01300   101000             NOP
0396 01301   101000             NOP
0397 01302   101000             NOP
0398 01303   101000             NOP
0399 01304   0 01 01000         JMP    1000
0400 01305   0 01 01254 WRT4    JMP    WRT6
0401 01306   0 02 01207 WRT5    LDA    WRIT
0402 01307   0 04 01342         STA    TM00
0403 01310   0 01 01254         JMP    WRT6
0404                            EJCT

                        END PATCH
                        GO START AGAIN

                        GET A POSITIVE NUMBER
                        SET FLAG PLUS, IT MAY BE ZERO
                        EXIT
```

```
0405 01311   0 000000   DMC  DAC   **                                          0405
0406 01312   14 1710          OCP   '1710      STOP WRITE, JUST IN CASE        0406
0407 01313   0 02 01325       LDA   DMC2       STARTING ADDRESS OF NEW ACTIVE BUFFER 0407
0408 01314   0 04 00020       STA   '20        STORE FOR CHANNEL 1             0408
0409 01315   0 13 01324       IMA   DMC1       INTERCHANGE BUFFER ADDRESSES    0409
0410 01316   0 04 01325       STA   DMC2       *                               0410
0411 01317   0 02 01327       LDA   DME2       GET ENDING ADDRESS              0411
0412 01320   0 04 00021       STA   '21        DMC CHANNEL 1 ENDING ADDRESS    0412
0413 01321   0 13 01326       IMA   DME1       INTERCHANGE ENDING ADDRESSES    0413
0414 01322   0 04 01327       STA   DME2       *                               0414
0415 01323  -0 01 01311       JMP*  DMC        EXIT                            0415
0416                     *                                                     0416
0417 01324   0 001436   DMC1 DAC   BUF1       *                               0417
0418 01325   0 003442   DMC2 DAC   BUF2       * INITIALIZED VALUES OF BUFFERS' 0418
0419 01326   0 003441   DME1 DAC   END1       *                               0419
0420 01327   0 005445   DME2 DAC   END2       *                               0420
0421 01330   000000     WF   BSZ   1          WRITE FLAG, ZERO INDICATES WRITE IN PROCESS 0421
0422 01331   000000     ACT  BSZ   1          ACTIVE DRIVE INDICATOR          0422
0423 01332   000000     PAS  BSZ   1          PASSIVE DRIVE INDICATOR         0423
0424 01333   000000     TM01 BSZ   1          DRIVE 0, OPERATIONAL MARKER     0424
0425 01334   000000     TM11 BSZ   1          DRIVE 1, OPERATIONAL MARKER     0425
0426 01335   000000     TM02 BSZ   1          DRIVE 0, CYCLE DOWN MARKER      0426
0427 01336   000000     TM12 BSZ   1          DRIVE 1, CYCLE DOWN MARKER      0427
0428 01337   000000     TM03 BSZ   1          DRIVE 0, REWIND MARKER          0428
0429 01340   000000     TM13 BSZ   1          DRIVE 1, REWIND MARKER          0429
0430 01341   000000     TMX4 BSZ   1          EOF FLAG (AT END OF TAPE)       0430
0431 01342   000000     TM00 BSZ   1          OVERALL STATUS MARKER           0431
0432                          EJCT                                           0432
```

```
0433 01343   0 000000   FULL DAC   **                                          0433
0434 01344   0 02 01400       LDA   BEG2    BEGINNING ADDRESS OF PASSIVE BUFFER(DELTA)   0434
0435 01345   0 04 01376       STA   DRAD    INDIRECT ADDRESS FOR BUFFER STORAGE          0435
0436 01346   0 13 01377       IMA   BEG1    CHANGE WITH ACTIVE BUFFER                    0436
0437 01347   0 04 01400       STA   BEG2                                               0437
0438 01350   0 02 01376       LDA   DRAD    LOAD POINTER                                 0438
0439 01351   0 06 00546       ADD   P4      MOVE TO FIRSR LOC                            0439
0440 01352   0 04 01376       STA   DRAD    RESTORE POINTER                              0440
0441 01353   0 02 01402       LDA   ENB2    LAST ADDRESS IN PASSIVE BUFFER               0441
0442 01354   0 04 01375       STA   DREA    USED TO DETERMINE FULL BUFFER                0442
0443 01355   0 13 01401       IMA   ENB1    CHANGE WITH ACTIVE BUFFER                    0443
0444 01356   0 04 01402       STA   ENB2                                               0444
0445 01357   0 02 01324       LDA   DMC1    CHECK DMC ADDRESS WITH NEW ACTIVE BUFFER     0445
0446 01360   0 11 01377       CAS   BEG1    THEY SHOULD NOT AGREE                        0446
0447 01361   0 01 01365       JMP   FUL1    OK, GO WRITE A RECORD                        0447
0448 01362   0 01 01364       JMP   *+2     NO GOOD, CHANGE DMC ADDRESS                  0448
0449 01363   0 01 01365       JMP   FUL1    OK                                           0449
0450 01364   0 10 01311       JST   DMC     THIS ROTUINE CHANGES THE DMC ADDRESS         0450
0451         001365     FUL1 EQU   *                                                  0451
0452 01365   0 02 01330       LDA   WF                                               0452
0453 01366   100400           SPL           WAS IT PLUS                              0453
0454 01367   0 01 01373       JMP   *+4     NO ALL OK GO START WRITE                  0454
0455 01370   0 10 00000       CALL  FORT1                                            0455
0456 01371   000000           HLT                                                    0456
0457 01372   0 01 01371       JMP   *-1     DONT RESTART                             0457
0458 01373   0 10 01207       JST   WRIT                                             0458
0459 01374  -0 01 01343       JMP*  FULL    EXIT                                     0459
0460                    *                                                          0460
0461 01375   0 003441   DREA DAC   END1    ENDING ADDRESS OF ACTIVE BUFFER          0461
0462 01376   0 001436   DRAD DAC   BUF1    BEGINNING ADDRESS OF ACTIVE BUFFER       0462
0463 01377   0 001436   BEG1 DAC   BUF1    BEGINNING ADDRESS OF ACTIVE BUFFER       0463
0464 01400   0 003442   BEG2 DAC   BUF2    BEGINNING ADDRESS OF PASSIVE BUFFER      0464
0465 01401   0 003441   ENB1 DAC   END1    ENDING ADDRESS OF ACTIVE BUFFER          0465
0466 01402   0 005445   ENB2 DAC   END2    ENDING ADDRESS OF PASSIVE BUFFER         0466
0467 01403   0 005446   ABUF DAC   BUF3                                            0467
0468 01404   0 005446   BPT  DAC   BUF3                                            0468
0469         001405     ES02 EQU   *                                               0469
0470                    *                                                          0470
0471                    *                                                          0471
0472         001436     BUF1 EQU   *+25                                            0472
0473         003441     END1 EQU   BUF1+1027                                       0473
0474         003442     BUF2 EQU   BUF1+1028                                       0474
0475         005445     END2 EQU   BUF2+1027                                       0475
0476         005446     BUF3 EQU   BUF2+1028                                       0476
0477                         SETB  ES00                                            0477
```

000F	000602A	00F0	000627A	00FF	000576A	0F00	000626A
0FFF	000572A	32HZ	001171A	A45	000504A	A90	000506A
ABUF	001403A	AC1	000637A	AC2	000640A	AC3	000641A
ACT	001331A	ANG	001166A	B1	000531A	B10	000542A
B11	000543A	B12	000544A	B13	000545A	B14	000546A
B15	000547A	B16	000550A	B2	000532A	B3	000533A
B4	000534A	B5	000535A	B6	000536A	B7	000537A
B8	000540A	B9	000541A	BB1	000502A	BEG1	001377A

BEG2	001400A	BPT	001404A	BUF1	001436A	BUF2	003442A
BUF3	005446A	BUFA	001056A	BUFB	001057A	CB1	000511A
CB10	000522A	CB11	000523A	CB12	000524A	CB13	000525A
CB14	000526A	CB15	000527A	CB16	000530A	CB2	000512A
CB3	000513A	CB4	000514A	CB5	000515A	CB6	000516A
CB7	000517A	CB8	000520A	CB9	000521A	CN1	000567A
CN10	000600A	CN11	000601A	CN12	000602A	CN13	000603A
CN14	000604A	CN15	000550A	CN16	000500A	CN2	000570A
CN3	000571A	CN4	000572A	CN5	000573A	CN6	000574A
CN7	000575A	CN8	000576A	CN9	000577A	CTR	001167A
DMA	001204A	DMC	001311A	DMC1	001324A	DMC2	001325A
DME1	001326A	DME2	001327A	DPT0	000044A	DPTD	000042A
DPTM	000044A	DPTT	000040A	DRAD	001376A	DREA	001375A
DUMY	000635A	ECNT	001062A	ENB1	001401A	ENB2	001402A
END1	003441A	END2	005445A	ENDA	001060A	ENDB	001061A
ES00	000100A	ES01	001207A	ES02	001405A	F000	000553A
F0FF	000630A	FF00	000557A	FF0F	000631A	FFF0	000563A
FFFF	000566A	FLAG	001170A	FUL1	001365A	FULL	001343A
LDUM	000632A	LSDB	000634A	M1	000566A	M10	000610A
M11	000607A	M12	000606A	M128	000560A	M129	000521A
M16	000563A	M17	000524A	M18	000605A	M2	000530A
M256	000557A	M257	000520A	M3	000527A	M32	000562A
M33	000523A	M4	000565A	M5	000526A	M512	000556A
M513	000517A	M6	000612A	M64	000561A	M65	000522A
M7	000611A	M8	000564A	M9	000525A	MAX	001164A
MBB1	000566A	MIN	001165A	N1	000531A	N10	000561A
N11	000562A	N12	000563A	N13	000564A	N14	000565A
N15	000530A	N16	000566A	N2	000551A	N3	000552A
N4	000553A	N5	000554A	N6	000555A	N7	000556A
N8	000557A	N9	000560A	NOGO	001201A	ONE	000510A
P0	000500A	P1	000550A	P10	000616A	P11	000617A
P12	000620A	P127	000577A	P128	000541A	P15	000602A
P16	000544A	P18	000621A	P2	000547A	P24	000622A
P255	000576A	P256	000540A	P3	000604A	P31	000601A
P32	000543A	P4	000546A	P5	000613A	P511	000575A
P512	000537A	P6	000614A	P63	000600A	P64	000542A
P7	000603A	P8	000545A	P9	000615A	PAS	001332A
PBB1	000502A	PI10	000070A	PRIM	001055A	RC1	001063A
RNGE	000633A	TIME	000624A	TM00	001342A	TM01	001333A
TM02	001335A	TM03	001337A	TM11	001334A	TM12	001336A
TM13	001340A	TMPC	000046A	TMPR	000026A	TMX4	001341A
WAIT	001132A	WAT1	001142A	WAT2	001147A	WAT3	001154A
WAT4	001152A	WF	001330A	WRIT	001207A	WRT1	001243A
WRT2	001250A	WRT3	001251A	WRT4	001305A	WRT5	001306A
WRT6	001254A	WRT7	001260A	XI	001160A	XI2	001162A
ZERO	000500A						

0000 WARNING OR ERROR FLAGS

DAP-16 MOD 2 REV D 06-28-71

AD-A035 033 HONEYWELL INC ST PETERSBURG FLA AEROSPACE DIV F/G 17/7
STANDARD PRECISION NAVIGATOR/GEANS MODIFICATIONS FOR EAR MOTION--ETC(U)
NOV 76 D GIONET, P E HALL, S SAMSEL F33615-74-C-1068
UNCLASSIFIED 176-13551 AFAL-TR-76-71 NL

5 OF 5
AD
A035033



END
DATE
FILMED
3-77

```
C FORTRAN SUBROUTINE TO INTERFACE WITH THE ANG.  RECORD PROGRAM 10/29/75                PAGE    1
C FORTRAN SUBROUTINE TO INTERFACE WITH THE ANG.  RECORD PROGRAM 10/29/75
      SUBROUTINE FORT(IBUF)
      DIMENSION IBUF(1),IDEG(5),XMIN(5)
      CALL SSWTCH(2,ISW)
      GO TO (5,2),ISW
2     CONTINUE
      WRITE(1,1000)
5     CONTINUE
      J=IBUF(1)
      DO 10 I=1,J
      N=7*(I-1)
      AMAX= FLOAT(IBUF(N+6))*2.**-15
      CALL CONV (AMAX,IDEG(1),XMIN(1),0)
      AMIN= FLOAT(IBUF(N+7))*2.**-15
      CALL CONV (AMIN,IDEG(2),XMIN(2),0)
      SIGMA= ((32768.*FLOAT(IBUF(N+4))+FLOAT(IBUF(N+5)))*2.**-30)/1024.
      AMEAN=(( 32768.*FLOAT(IBUF(N+2))+FLOAT(IBUF(N+3)))*2.**-15)/1024.
      SIGMA= SQRT(SIGMA-AMEAN**2)
      AMEAN= AMEAN+(FLOAT(IBUF(N+8))*2.**-15)
      CALL CONV(AMEAN,IDEG(3),XMIN(3),0)
      CALL CONV(SIGMA,IDEG(4),XMIN(4),0)
      DELTA= AMAX-AMIN
      CALL CONV(DELTA,IDEG(5),XMIN(5),1)
      WRITE(1,1002) I,(IDEG(L),XMIN(L),L=1,5)
10    CONTINUE
1002  FORMAT(//,I3,2X,(2X,I3,2X,F6.3))
1000   FORMAT(1H /3HREC,5X,3HMAX,15X,3HMIN,13X,4HMEAN,12X,5HSIGMA,
     2 5HDELTA//,5X,5(3X,3HDEG,4X,3HMIN))
      RETURN
      END
      SUBROUTINE CONV(DATA,IDEG,XMIN,K)
      DATA1=DATA
      IF(K.NE.0) GO TO 10
      IF(DATA.LT.0.) DATA1=DATA1+2.
10    CONTINUE
      DATA1=DATA1*180.
      IDEG=DATA1
      XMIN=(DATA1-FLOAT(IDEG))*60
      RETURN
      END
$0
```

```
C FORTRAN SUBROUTINE TO INTERFACE WITH DELTA V RECORD PROGRAM  10/29/75                    PAGE    1
C FORTRAN SUBROUTINE TO INTERFACE WITH DELTA V RECORD PROGRAM  10/29/75
      SUBROUTINE FORT(IBUF)
      DIMENSION IBUF(1)
      CALL SSWTCH(2,ISW)
      GO TO (5,2),ISW
2     CONTINUE
      WRITE (1,100)
5     CONTINUE
      J=IBUF(1)
      DO 10 I=1,J
      N=7*(I-1)
      SIGMA = (32768.*FLOAT(IBUF(N+4))+FLOAT(IBUF(N+5)))/1024.
      AMEAN =  (32768.*FLOAT(IBUF(N+2))+FLOAT(IBUF(N+3)))/1024.
      SIGMA=SQRT(SIGMA-AMEAN**2)
      AMEAN= AMEAN+FLOAT(IBUF(N+8))
      WRITE(1,110) I,IBUF(N+6),IBUF(N+7),AMEAN,SIGMA
10    CONTINUE
      RETURN
100   FORMAT (//5X,4HRECD,2X,3HMAX,2X,3HMIN,6X,4HMEAN,8X,3HDEV)
110   FORMAT(5X,I3,2X,I5,2X,I5,2X,F10.5,2X,F10.5)
      END
$0
```

```
      SUBROUTINE FORT1                                          PAGE    1
      SUBROUTINE FORT1
A     OCP :1610
      WRITE(1,100)
100   FORMAT (43HOUT OF TIME DURING REWRITE,REPEAT LAST FILE)
      RETURN
      END
$0
```

MAP FOR ANG

*LOW	00064	*START	00064	*HIGH	15456	*NAMES	51076	*COMN	37777						
*BASE	00275	*BASE	01410	DUMY	00635	AC1	00637	AC2	00640	AC3	00641	FORT	10000	CONV	10540
FORT1	10640	SQRTX	10700	SQRT	10700	E$21	11014	FLOAT	11074	C$12	11104	C$21	11136	S$22	11175
A$22	11203	M$22	11413	D$22	11604	REAL	11764	L$22	11764	H$22	11774	N$22	12012	SLITE	12024
SLITET	12040	SSWTCH	12061	M$11X	12136	M$11	12136	F$AT	12216	L$33	12312	F$W1	12326	F$IO	12466
F$L3	13011	F$L1	13011	F$L5	13016	F$L6	13016	F$L2	13016	F$AR	13022	F$CB	13202	ARG$	15134
F$ER	15154	F$HT	15164	AC4	15225	AC5	15226	O$AP	15230	O$AC	15302	O$AF	15306	OUPT	15316
O$AB	15316	O$AS	15425	EOM	15425										

MAP for DELTA V

*LOW	00064	*START	00064	*HIGH	15106	*NAMES	51120	*COMN	37777								
*BASE	00315	*BASE	01410	DUMY	00635	AC1	00637	AC2	00640	AC3	00641	FORT	10000	FORT1	10322		
SQRTX	10362	SQRT	10362	E$21	10476	FLOAT	10556	C$12	10566	S$22	10625	A$22	10633	M$22	11043		
D$22	11234	REAL	11414	L$22	11414	H$22	11424	N$22	11442	SLITE	11454	SLITET	11470	SSWTCH	11511		
M$11X	11566	M$11	11566	F$AT	11646	L$33	11742	F$W1	11756	F$IO	12116	F$L3	12441	F$L1	12441		
F$L5	12446	F$L6	12446	F$L2	12446	F$AR	12452	F$CB	12632	ARG$	14564	F$ER	14604	F$HT	14614		
AC4	14655	AC5	14656	O$AP	14660	O$AC	14732	O$AF	14736	OUPT	14746	O$AB	14746	O$AS	15055		
EOM	15055																

PATCHES

```
400 NOT USED
401  OCP '1710      ; STOP WASTE
402  LDA # 414      ;
403  STA  20        ;  LOAD START ADR
404  LDA # 415      ;
405  STA '21        ;  LOAD END ADR
406  OCP '0310
407  OCP '1010
410  CRA
412  STA #
413  JMP * 400
414  1400
415  1402
416  1330
```


☆ U. S. GOVERNMENT PRINTING OFFICE: 1976 — 757-001/117